DEPARTMENT OF THE ARMY

CORPS OF ENGINEERS

MISSISSIPPI RIVER COMMISSION

PLANS FOR ELIMINATION OF SHOALING IN NEW CASTLE-FINNS POINT RANGES DELAWARE RIVER

MODEL INVESTIGATION

TECHNICAL MEMORANDUM NO. 2-259

WATERWAYS EXPERIMENT STATION

VICKSBURG, MISSISSIPPI

MRC-WES-150-8-48

AUGUST 1948

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **AUG 1948**	2. REPORT TYPE	3. DATES COVERED **00-00-1948 to 00-00-1948**
4. TITLE AND SUBTITLE **Plans for the Elimination of Shoaling in the New Castle-Finns Point Ranges, Delaware River: Model Investigation**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **U.S. Army Corps of Engineers,Waterway Experiment Station,3903 Halls Ferry Road,Vicksburg,MS,39180**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a REPORT **unclassified**	b ABSTRACT **unclassified**	c THIS PAGE **unclassified**	**Same as Report (SAR)**	**116**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

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PLANS FOR ELIMINATION OF SHOALING

IN NEW CASTLE-FINNS POINT RANGES, DELAWARE RIVER

MODEL INVESTIGATION

SYNOPSIS

This memorandum constitutes a comprehensive report on a model study of the New Castle and Finns Point Ranges section of the Delaware River ship channel. The model investigation was authorized by the Chief of Engineers, U. S. Army, on 10 September 1940, and was conducted by the Waterways Experiment Station during the period June 1941 to January 1945.

The problem with which the model study was concerned was that of shoaling in the above-mentioned ranges, where the annual shoaling rate averages about 2,000,000 cu yd. The purpose of the study was to predetermine the effectiveness of various proposed improvement plans in eliminating or reducing maintenance dredging in the ship channel. Plans tested consisted of: (1) installing structures designed to reduce shoaling by directing tidal currents into conformity with the dredged channel; (2) realigning the navigation channel to conform more nearly to the alignments of existing tidal currents; and (3) constricting the cross-sectional area of the channel to increase flood and ebb velocities in the channel reach subject to excessive shoaling. Tests were conducted on a fixed-bed model in which transportation and deposition of shoaling material, as affected by the various hydraulic forces, were reproduced and studied.

The model study indicated that any of plans 1, 4, 18, and 21 (described in paragraphs 29, 38, 65, and 72, respectively) would decrease to some extent the present rate of shoaling in the channel, and would improve the alignments of flood and ebb currents in the vicinity of Pea Patch Island. It is doubtful, however, that the benefits accruing from installation of any of these plans in the river would be commensurate with the cost of construction.

PART I: INTRODUCTION

The Problem

1. The problem with which the model investigation was concerned was that of shoaling in the New Castle and Finns Point Ranges below Pea Patch Island in the Delaware River ship channel. The location of the problem area is shown on figures 1 and 2. The average annual shoaling rate in these ranges is about 2,000,000 cu yd. New Castle and Finns Point Ranges are each approximately 2 mi long with a navigation channel 800 ft wide having a project depth of 40 ft.

2. Little is known of the origin or the manner of travel and deposition of the material that shoals the Delaware River channel. It is generally believed that the original source of shoaling material is in the upper reaches of the river, and that this material is silt brought downstream during high discharges and kept in a more or less constant state of agitation by the action of tidal currents. The silt is apparently swept upstream by flood tides and downstream by ebb, gradually settling to the bottom in the deeper areas of the channel and in areas not subjected to current action of sufficient magnitude to keep the material in suspension. It also appears reasonable to assume that a large percentage of the material is deposited in the shoal areas of the river, whence it is swept into the dredged channel by cross-channel currents of the flood and ebb tides.

The Model Study

3. The purpose of the model study was to investigate and analyze

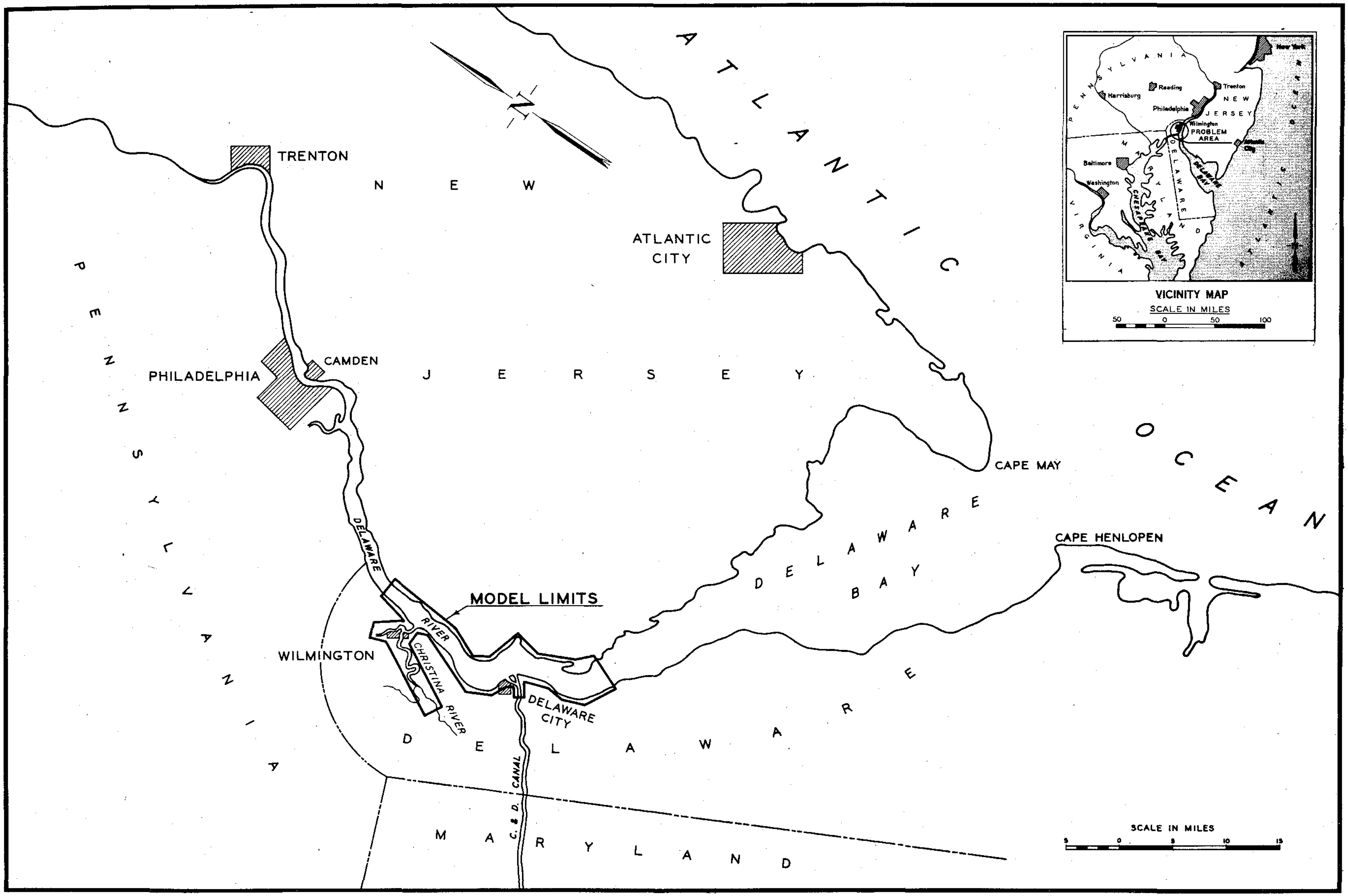


Fig. 1. Location map

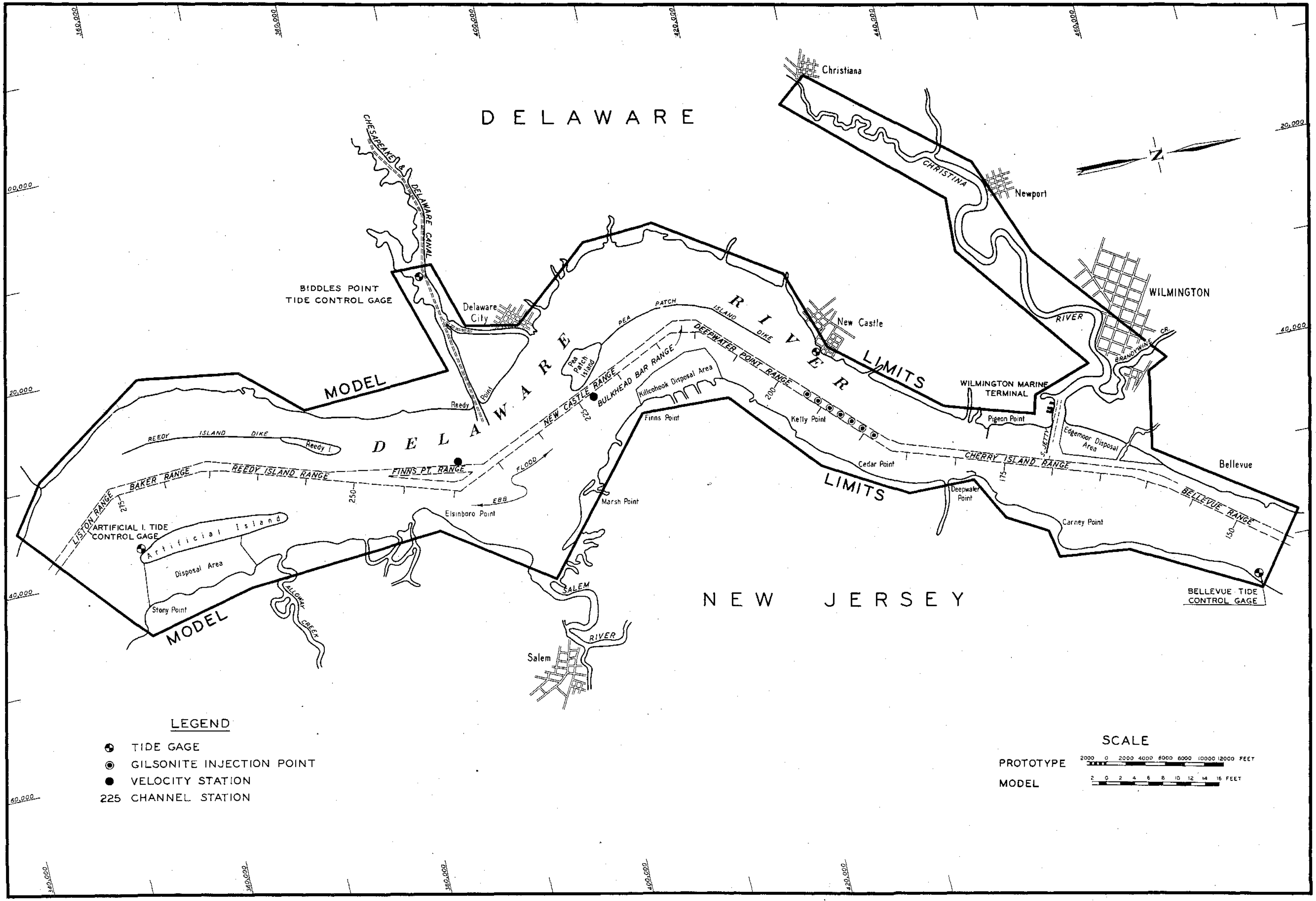


Fig. 2. General layout

the shoaling problem described above and to develop the most efficient plan for the reduction or elimination of the heavy shoaling in the ship channel. In general, the proposed plans tested were designed to reduce shoaling either by directing tidal currents into conformity with the course of the dredged channel, by realigning the project channel to conform more nearly to existing tidal currents, or by constricting the cross-sectional area of the channel to effect local increases in flood and ebb velocities in the channel reach subject to excessive shoaling.

4. The accurate reproduction of observed prototype tidal heights, current directions, and current velocities, and a reasonably close reproduction of the prototype distribution of shoaling in the different sections of the channel were required for a reliable hydraulic model study of the problem. Accordingly, the investigation consisted of the following three phases: (a) hydraulic verification, or adjustment of the model to reproduce accurately the observed hydraulic phenomena of the prototype; (b) shoaling verification, or development of the technique of introducing shoaling material into the model so as to reproduce prototype shoaling distributions; and (c) testing of the various proposed plans of improvement to determine their effects upon shoaling in the channel.

5. The model study was authorized by the Chief of Engineers in second indorsement dated 10 September 1940 to letter from the District Engineer, Philadelphia District, CE, dated 22 August 1940, subject, "Proposed Delaware River Model Studies". The study was conducted by the Hydraulics Division of the Waterways Experiment Station intermittently during the period June 1941 to January 1945. Close liaison was maintained

between the Experiment Station and the Philadelphia District through correspondence, conferences, and inspections of the model throughout the course of the study. Semi-monthly progress reports were submitted during the period of testing, and special reports giving complete analyses of the various phases of the study were submitted after completion of the model tests involved. This report comprehends and supersedes all previous reports on the New Castle-Finns Point Ranges model study.

PART II: THE MODEL

Description

6. The model study of the New Castle-Finns Point Ranges was conducted on a model formerly used for studies of shoaling in Deepwater Point Range, Wilmington Harbor, and the Delaware River entrance to the Chesapeake and Delaware Canal. Reproduced in the model were the Delaware River from Artificial Island to a point one mile above Bellevue, the tidal portions of the Christina River and Brandywine Creek, and about three miles of the Chesapeake and Delaware Canal. Model limits in relation to the prototype can be seen by referring to the location and layout maps on figures 1 and 2.

7. The model was of the fixed-bed type, all areas being reproduced in concrete molded to prototype configurations by means of sheet-metal templets, and was housed in a wooden shelter to protect it from effects of the weather. The model was constructed to linear-scale ratios, model to prototype, of 1:800 horizontally and 1:80 vertically. These ratios fixed the following model-to-prototype relationships: slope scale, 10:1; velocity scale, 1:8.74; and time scale, 1:89.4. Thus, one prototype tidal cycle of 12.42 hours was reproduced in the model in 8.33 minutes.

8. The model was molded to the hydrography as shown by the Delaware River survey of 1932, supplemented by partial surveys of 1938. The Chesapeake and Delaware Canal was molded in the model as a uniform section with a bottom width of 250 ft, a depth of 27 ft, and side slopes of 1 on 2. The Christina River and Brandywine Creek were molded to partial surveys of 1926, 1936, 1938, 1939 and 1940. All of the

surveys used were made by the Philadelphia District, CE.

Automatic tidal apparatus

9. Tide reproduction. Observed prototype tides and tidal currents were reproduced in the model by means of three identical tide reproducers, located at Artificial Island, Bellevue, and in the Chesapeake and Delaware Canal. Each of these apparatus consisted of the following component parts: (a) a movable, motorized waste weir installed across a pit at the end of the model; (b) a centrifugal pump for supplying water to this pit on the model side of the waste weir; (c) a waste line connecting the opposite side of the waste weir to the sump; and (d) an automatic control apparatus located within the model for regulating the operation of the waste weir to maintain proper tidal elevations in the model. Thus, the correct tidal flow was reproduced in the model by maintaining correct tide heights through synchronous operation of the three tide reproducers.

10. Tide control. Each of the automatic control devices for regulating the operation of the motorized waste weirs was equipped with a cam (cut to a polar plot of the prototype mean tide) rotated by a synchronous motor at a speed determined by the computed model time scale. Riding vertically on this cam was a rod carrying a pair of electric contacts, one above the other, which rose and fell in accordance with the plotted tide curve. A third contact, placed between this pair of contacts with very slight clearances above and below, was attached to a rod supported by a float which rose and fell with the surface of the water in the control pit. The control pit was connected to the model by means of pipes, allowing the free passage of water between the model and the

control pit. Thus, whenever the water surface in the model rose slightly above or fell slightly below its proper elevation at any time during the tidal cycle, the float forced the middle contact to close the electric circuit through the upper or lower contacts, respectively. Closing of the upper circuit actuated the motorized waste weir in a downward direction, directing more of the pump output back to the sump and causing the water surface in the model to fall to its proper elevation; closing of the lower circuit reversed the direction of the weir, causing the model water surface to rise to its proper elevation. Since a variation in the amount of movement of the motorized weir was required during the tidal cycle, it was necessary to control the movement of the weir by an interrupter which consisted of a cam, mercury-tube circuit breaker, and a motor. The tide thus simulated was a very accurate reproduction of the observed prototype mean tide.

11. Tide recorder. Each automatic control apparatus was equipped with a recording device which inked on a roll of paper a continuous record of the model tide curve, superimposed upon the prototype curve being reproduced. The prototype curve was inked by a pen riding on the plotted cam, while the model reproduction of this curve was superimposed by a pen riding on a float in the control pit. This feature permitted a visual check on the model tide reproduction at all times.

Shoaling apparatus

12. Shoaling was reproduced in the model by injecting finely-ground gilsonite, a commercial asphaltic compound with a specific gravity of approximately 1.035. The equipment used for injecting gilsonite into

the model consisted of a mixing tank containing a motor-driven propeller which kept the supply of gilsonite and water thoroughly mixed, and a centrifugal pump and a system of pipes and valves for distributing the mixture to the points of injection. The valves were adjusted so that the amounts of material introduced for the various tests were as nearly identical as practicable. At the end of each model test, the shoaling material deposited in the model ship channel was picked up hydraulically by means of a flexible tube equipped with a small dustpan-like head and connected to a very small centrifugal pump. The gilsonite thus picked up was separated from the water by means of a centrifuge and measured.

Gages

13. The model was equipped with point gages graduated so that tidal heights could be measured to the nearest 0.08 ft (prototype). Tidal heights were measured at selected stations at half-hourly intervals throughout a tidal cycle.

PART III: VERIFICATION OF THE MODEL

14. Before the predictions of model tests of proposed plans could be accepted as trustworthy, the reliability of the model first had to be established. Thus, it was necessary to adjust the model to such a degree as to verify its ability to reproduce accurately the known action of the prototype. The verification of the New Castle-Finns Point Ranges model consisted of two phases: (a) hydraulic adjustment, which brought tidal heights, current directions, and current velocities into close agreement with corresponding phenomena measured in the prototype; and (b) shoaling adjustment, which resulted in establishing a model technique that would reproduce with sufficient accuracy the percentile distribution of channel shoaling as measured in the prototype.

Hydraulic Verification

Adjustment of tides

15. As previously stated, the initial step in the adjustment of the model was the adjustment of the tide-reproducing equipment so that prototype mean tides were reproduced to scale at the three control stations. When this had been accomplished, tidal heights at intermediate stations were adjusted by varying the roughness of the model bed. The model was operated under mean-tide conditions only, and prototype data were available to check the accuracy with which the model reproduced tides throughout the channel length. Plate 1 shows plots of both model and prototype mean-tide curves at the Bellevue, New Castle, Reedy Point, and Artificial Island gages.

Adjustment of currents

16. In order to adjust model current velocities and current directions to agree with observed prototype data, it was necessary to make further refinements in the roughness adjustment of the model channel. The degree of accuracy with which prototype velocities were reproduced in the model can be seen from an inspection of plate 2, which shows plots of model and prototype mean-tide velocity curves. Comparisons of model and prototype ebb and flood current directions, obtained in both model and prototype by use of floats, are shown on plates 3 and 4. In comparing these current directions, it should be kept in mind that the model reproduced only the mean tide, while prototype observations were necessarily made on days having slightly different tidal variations. Photographs 1 and 2 show model surface-current patterns (as indicated by confetti) in the problem area at strength of ebb and flood flows, respectively.

Shoaling Verification

17. The operating technique developed in hydraulic verification of the model was followed exactly throughout the shoaling verification and all subsequent model tests. Shoaling verification consisted of the cut-and-try development of a method and volume of shoaling-material injection which would reproduce in the model a distribution of shoaling in the channel comparable to shoaling measured in the prototype. Although many trial tests were made during this phase of the study, in progressive attempts to develop the required technique, only the final successful procedure is described.

Assumed manner of prototype shoaling

18. Since so little is known of the manner of deposition and movement of shoaling material in the Delaware River, it was essential, prior to adjustment of the model, to arrive at basic assumptions as to the nature of prototype shoaling. The following assumptions were based on a study of all prototype data available:

- a. That the original source of all shoaling material in the Delaware River is in the upper reaches of the river, while upstream and downstream movement of such material occurs with flood and ebb tide.
- b. That the general movement of silt is progressively downstream, since ebb flow is greater in magnitude than flood.
- c. That shoaling is the result of both the deposition of suspended silt and the movement of this light silt (after deposition) back and forth along the river bottom with varying tidal flow.

19. It is evident, if the above assumptions present a correct picture of the action of shoaling material in the prototype, that maximum shoaling would occur under two conditions: (a) in areas of the river where velocities of flood or ebb flows are too low to prevent rapid deposition; and (b) in portions of the channel where bottom velocities (particularly those during the ebb period) are so low that movement of material previously deposited is at a minimum.

Method of operation

20. With the above assumptions in mind, it was decided that shoaling could best be reproduced in the model by injecting into the stream a shoaling material consisting of a mixture of gilsonite and water. It was found by trial that a mixture consisting of 7 parts of gilsonite to 100 parts of water would pass freely through the injection apparatus,

would introduce a volume of material which the model currents could disperse without creating unnatural bars at the points of injection, and would produce easily measurable deposits over the problem area. Shoaling material was introduced into the channel well above the problem area between stations 189+175 and 197+250 for five consecutive ebb periods (hours 2.5 to 6.0) in order to permit the material to move and deposit naturally throughout the model. The gilsonite, being a very light material, moved downstream and gradually settled to the bottom of the channel where it was moved upstream and downstream with varying phases of the tide, gradually progressing downstream or accumulating in those portions of the channel in which velocities were too low to move it further. Through the reproduction of a combination of deposition and movement along the bed, the percentile distribution of prototype shoaling in the three shoaling ranges of the problem area was reproduced with a reasonable degree of accuracy. At the end of the injection period, operation of the model was discontinued and the gilsonite within the problem area was collected and measured. In order to check the accuracy of shoaling distribution in the problem area, the volumes of shoaling deposited were measured by sections (figure 3) as follows:

- a. Section 1 (New Castle Range), station 226+000 to station 229+000.
- b. Section 2 (New Castle Range), station 229+000 to station 236+029.
- c. Section 3 (Finns Point Range), station 236+029 to station 246+000.

Results

21. The total volume of shoaling obtained in the problem area

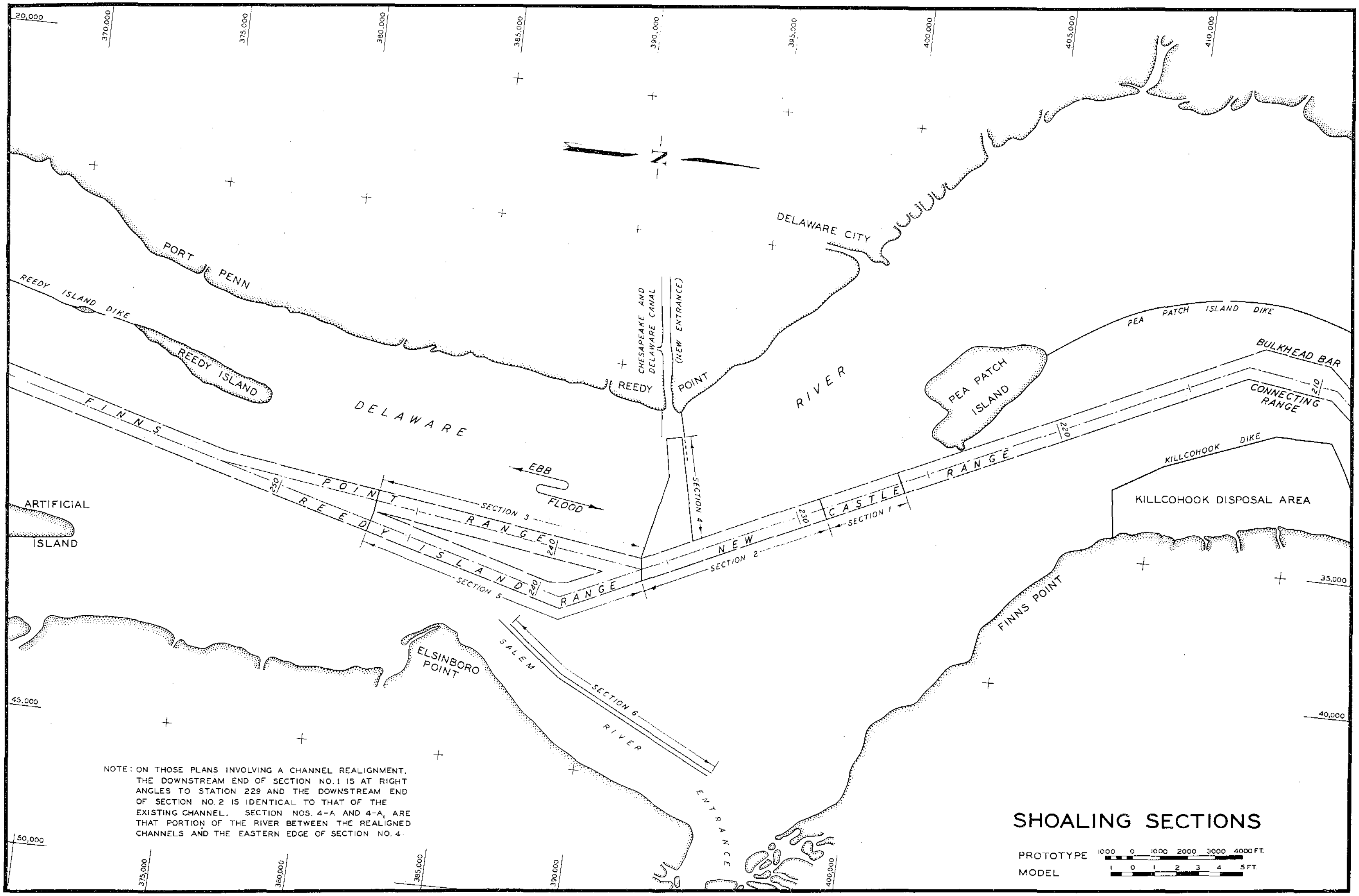


Fig. 3. Shoaling sections

during the shoaling verification tests was 2643 cc. The following tabulation presents a comparison of the percentile shoaling distribution by sections in the model and prototype:

Section	Model (Per cent of total)	Prototype (Per cent of total)
1	18.0	16.7
2	52.0	68.2
3	30.0	15.1

Discussion of Results

22. The results of hydraulic verification of the model indicated a high degree of similitude between hydraulic phenomena in the model and prototype. Furthermore, results of the shoaling verification indicated that hydraulic forces in the model transported and deposited shoaling material in close similitude with prototype shoaling. The model was therefore considered verified and the model operating technique established, so that reliable tests could be undertaken of proposed plans for reducing shoaling.

PART IV: TESTS OF PROPOSED IMPROVEMENT PLANS

Testing Procedure

Method of operation

23. The model operating procedure developed during the verification phase of the study, as described in the preceding part of this report, was followed as closely as possible in all tests of proposed improvement plans. Measurements of tidal heights and current velocities, photographs of current patterns, and volumes of shoaling were obtained for each condition tested. Tide and velocity observations were always made for two consecutive tidal cycles, the results presented herein being in each case the mean of two cycles. In conducting shoaling tests, two consecutive identical tests were made of each proposed plan of improvement; thus, the shoaling results presented in this report are in each case the mean of two separate -- but identical -- tests.

Method of analyzing results

24. Evaluation of shoaling volumes. In order to evaluate the effects of each plan upon shoaling of the navigation channel, the volume of shoaling obtained in each test of an improvement plan was compared to that obtained in a model test with no improvement plan installed. The volumetric difference obtained in this manner indicated the increase or decrease in shoaling which could be attributed to the improvement plan in question. A test in which no improvement plan was installed in the model is referred to in this report as a "base test", since it constitutes a basis of comparison for determining

the effects of plans of improvement.

25. Interpretation of test results. In interpreting the results of the model tests, it should be kept in mind that the results of shoaling tests of improvement plans are not to be considered as strictly quantitative in nature and must be interpreted mainly on a qualitative basis. It is believed that tests of improvement plans resulting in shoaling indices greater than 0.90 should not be considered as indicating a significant improvement over existing conditions, as the accuracy of the model in reproducing volumes and distributions of shoaling under identical test conditions is considered to be within approximately 10 per cent.

26. Evaluation of tide curves. The tide curves shown on plates 9-23 represent observations taken at the two tide control stations. The minor fluctuations shown on these plates should not be interpreted as indications of the effect of the various improvement plans in the model, as the curves plotted show only the variations in operation of the automatic tide machines. These curves are presented only for the purpose of showing the consistency of the reproduction of the tides for each plan tested.

Base Test

27. Upon completion of the model verification, the results of the final verification test were established as being representative of existing conditions throughout the problem area. The shoaling results obtained in this test were used as the basis of comparison to determine the effectiveness of the various improvement plans tested; therefore, this test will be referred to hereinafter in this report as the "base test".

28. As a check on the ability of the model to repeat itself, duplicates of the base test and all other tests run on the model were made. The results of each test presented in this memorandum represent the average of two identical tests. At the end of the testing program, a rerun of the base test was conducted to check the operation of the model throughout the entire series of tests. The results of this test checked the results of the original base test within about two per cent.

Tests and Results

Plan 1

29. This plan consisted of a dike extending downstream from the lower end of Killcohook Dike for a distance of approximately 20,000 ft along the general alignment of the 6-ft contour (plate 5). The line of the dike then turned and connected with the New Jersey shore on a line parallel to and 700 ft west of the Salem River entrance channel. The purposes of this dike were to deflect the currents so as to bring them more nearly in line with the existing channels, and to increase existing current velocities through this reach by reducing the cross-sectional area of the river.

30. Installation of plan 1 in the model caused general increases in flood velocities at station 223+500 with no appreciable change in ebb velocity. The plan had no noteworthy effect on velocities at station 239+000. (See plate 9 for tide and velocity measurements.) There were slight changes in the direction of flood and ebb currents (photographs 3 and 4), the direction of flow being more in alignment with the existing channel than under basic conditions. The shoaling

index obtained for the test of plan 1 was 0.83 (table 1), indicating that the plan would decrease slightly the present rate of shoaling in the problem area.

Plan 2A

31. This plan consisted of a training dike beginning at the lower end of Pea Patch Island and extending downstream 7700 ft, on an alignment parallel to and 1300 ft west of the center line of the existing New Castle Range (plate 5). This dike was designed to keep the ebb flows of the main and secondary channels separated until their directions were parallel.

32. Installation of this plan in the model increased flood velocities at stations 223+500 and 239+000 and slightly decreased ebb velocities. (See plate 10 for tide and velocity measurements.) There was no appreciable change in the direction of flood and ebb currents (photographs 5 and 6). The shoaling index obtained for this test was 0.98 (table 1), indicating that the plan would have no appreciable effect on the rate of shoaling within the problem area. It may be noted, however, that the rate of shoaling in section 3 was slightly decreased, while that in sections 1 and 2 was slightly increased.

Plan 2B

33. Plan 2B was the same as plan 2A except that the length of the training dike was 5700 ft instead of 7700 ft (plate 5).

34. Installation of this plan caused slight increases in flood velocities at station 223+500 and slight decreases in ebb velocities at this station and at station 239+000. (See plate 11 for tide and velocity

measurements.) The shoaling index obtained for this test was 0.91 (table 1), indicating that the plan would cause a slight decrease in shoaling within the problem area; however, it was observed that deposits of shoaling material above the problem area were greater for the test of plan 2B than for the base test. The plan had no appreciable effect on the direction of flood and ebb currents (photographs 7 and 8).

General conditions for plans 3 through 8

35. It was assumed that the depths for the full width of the realigned or new channel in plans 3, 4, 5, 6, 7, and 8 were 40 ft wherever the existing soundings show depths less than 40 ft, and that the abandoned portion of the channel would eventually shoal to natural depths. The assumed natural depths were determined for each line of soundings by assuming a uniform slope of river bed between the first soundings outside the existing east and west channel limits that seemed to have been unaffected by channel dredging, and the existing channel was filled on an even slope between such soundings.

Plan 3

36. This plan consisted of a 6.5-degree change in the alignment of New Castle Range, beginning at channel station 223+000, with the downstream end of the relocated reach connecting with the present Finns Point Range extended (plate 5). The purpose of this plan was to realign the channel through this reach to conform to the general direction of the flood and ebb currents insofar as practicable.

37. The shoaling index obtained for the test of this plan was 0.89 (table 1), indicating that the plan would effect a slight reduction in

the rate of shoaling within the problem area. It may be noted that the rate of shoaling in section 3 was materially reduced, while that in section 1 was increased by approximately the same amount. There were slight increases in flood velocities at stations 223+500 and 239+000 with no appreciable change in ebb velocities. (See plate 12 for tide and velocity measurements.) The directions of flood and ebb currents were not appreciably affected by the change in channel alignment (photographs 9 and 10).

Plan 4

38. Plan 4 consisted of a combination of plans 1 and 3, as outlined in paragraphs 29 and 36 above (plate 5).

39. The shoaling index obtained for the test of this plan was 0.85 (table 1), indicating that the plan would cause some decrease in the rate of shoaling within the problem area. There were general increases in flood velocities at stations 223+500 and 239+000 with slight decreases in ebb velocities. (See plate 13 for tide and velocity measurements.) The alignment of flood and ebb currents was about the same as for the test of plan 1 (photographs 11 and 12).

Plan 5

40. This plan consisted of the realigned channel of plan 3 (paragraph 36) and the training dike of plan 2A (paragraph 31) with the dike turned 6.5 degrees to make it parallel to the realigned channel (plate 5).

41. The shoaling index obtained for the test of this plan was 1.16 (table 1), indicating that the plan would slightly increase the

present rate of shoaling within the problem area. The greater portion of this increase in shoaling occurred in section 1, sections 2 and 3 shoaling to about the same extent as observed during the base test. Flood velocities at station 223+500 were slightly increased with no appreciable change in ebb velocities. At station 239+000 flood velocities were generally increased, while ebb velocities were decreased. (See plate 14 for tide and velocity measurements.) The directions of flood and ebb currents were, in general, the same as for the test of plan 2A (photographs 13 and 14).

Plan 6

42. This plan consisted of the realigned channel of plan 3 (paragraph 36) and a dike similar to that of plan 1 (paragraph 29), except that the dike was located along the 10-ft contour instead of the 6-ft contour (plate 5). The purpose of this plan was to effect local increases in current velocities by reducing the cross-sectional area of the river.

43. The shoaling index obtained from the test of this plan was 0.87 (table 1), indicating that this plan would reduce to some extent the present rate of shoaling within the problem area. The greater portion of this reduction occurred in sections 1 and 2, the rate of shoaling in section 3 being about the same as observed during the base test. There was a general increase in flood velocities at station 223+500 with little change in ebb velocity. There was no appreciable change in velocities at station 239+000. (See plate 15 for tide and velocity measurements.) Both flood and ebb currents followed the alignment of the channel through sections 1 and 2, current directions in section 3 being

about the same as observed during the base test (photographs 15 and 16).

Plan 7

44. This plan consisted of the realigned channel of plan 3 (paragraph 36) and a training dike 4000 ft in length located 1600 ft east of the center line of the channel at the intersection of the realigned New Castle Range and the Finns Point Range extended (plate 5). The purpose of this dike was to direct the flood and ebb currents into alignment with the dredged channel.

45. The shoaling index obtained for the test of plan 7 was 0.99 (table 1), indicating that the plan would have no appreciable effect on shoaling within the problem area. The plan had no appreciable effect on current velocities at stations 223+500 and 239+000. (See plate 16 for tide and velocity measurements.) Flood currents followed the alignment of the dredged channel more closely than for plan 3 (photograph 18); however, the dike caused the ebb flow to cross the dredged channel at about station 232+500 (photograph 17).

Plan 8

46. This plan consisted of the realigned channel of plan 3 (paragraph 36) and a training dike parallel to and approximately 1600 ft east of the channel center line, and extending from station 222+000 to 226+000 (plate 5). The object of this dike was to direct ebb currents into alignment with the New Castle Range channel.

47. The shoaling index obtained for the test of this plan was 1.34 (table 1), indicating that the plan would materially increase the present rate of shoaling in the problem area. It may be noted that the

rate of shoaling in section 3 was only slightly increased, the greatest increase occurring in sections 1 and 2. Flood velocities at station 223+500 were increased, while there were general decreases in ebb velocities at this station. The plan had but little effect on velocities at station 239+000. (See plate 17 for tide and velocity measurements.) The direction of ebb currents was in alignment with the dredged channel; however, the direction of flood flow was generally across the channel (photographs 19 and 20).

Plan 9

48. This plan consisted of a training dike parallel to and approximately 2200 ft west of the center line of the Finns Point Range, and extending from station 238+000 to station 244+000 (plate 6). Inspection of current direction photographs for the base test indicated that ebb currents followed the existing channel alignment fairly well, but the flood currents divided and passed on both sides of Pea Patch Island. It was the purpose of this plan to guide the flood-tide currents past the Chesapeake and Delaware Canal entrance and into the New Castle Range channel, and thus increase flood velocities through the problem area.

49. After thorough consideration by both the Experiment Station and the District Engineer, it was decided to forego making a shoaling test of plan 9. Photographs of the model currents were made with this plan installed (photographs 21 and 22).

Plan 10

50. This plan consisted of a combination of plan 2A (paragraph 31)

and plan 9 as described in the preceding paragraph (plate 6). Since current directions as affected by plan 9 did not indicate an improvement over existing conditions, it was decided to forego testing of plan 10 entirely and test plans that showed promise of being more effective.

Plans 11, 11A, 11B, and 11C

51. Plan 11 consisted of a dike approximately 9400 ft long with its upstream end located 2400 ft west of the center line of the New Castle Range at station 213+700. From this point the dike extended downstream, roughly following the 6-ft contour, to the wharf on the east side of Pea Patch Island, where the dike connected with the island (plate 6). This plan was designed to direct the ebb currents into alignment with the main channel. Plan 11A consisted of a dike, roughly following the 18-ft contour from station 229+400 to station 235+800, and located 1600 ft east of and parallel to the center line of the New Castle Range ship channel. At station 235+800 the dike turned and connected with the New Jersey shore above Salem River. Plan 11B, an alternative to plan 11A, was the same as plan 11A except that the upstream end of the dike was extended to connect with the projecting point of the Killcohook disposal area, and the downstream section was not connected with the New Jersey shore but remained parallel to the channel. A third variation, plan 11C, consisted of a combination of plans 11A and 11B. This plan, if constructed in the prototype, would create a desirable disposal area. The object of these plans was to cut off the flow across the Salem Cove shoals which causes the flood currents to cross the ship channel just above Pea Patch Island.

52. Only photographic tests showing current directions were made of these 4 plans (photographs 23 through 30). It is apparent from these photographs that either of plans 11A, 11B, and 11C would effectively eliminate the flow across Salem Cove shoals, resulting in improved flow conditions in the river channel. However, due to the cost of actually building plans of this type, none were tested to determine shoaling effectiveness.

Plan 12

53. This plan consisted of: a dike extending from station 237+350, 1600 ft east of and parallel to the ship channel, to station 229+300, at which point it turned 13.5 degrees east and extended 2300 ft upstream; a dike similar to the structure of plan 2A; and extensions to both the north and south jetties of the Chesapeake and Delaware Canal (plate 6). The object of this plan was to cause the currents, normally flowing back and forth in the secondary channel west of Pea Patch Island, to flow through the main channel.

54. Only photographic tests showing current directions with this plan installed were made (photographs 31 and 32). The model study of the entrance to the Chesapeake and Delaware Canal indicated that further extensions to the jetties, other than the ones already authorized, would have harmful effects on the shoaling conditions in the entrance. Since this plan involved extensions to both the north and south jetties at the entrance to the canal, and since the greater portion of the dike called for in plan 12 would be located in relatively deep water, making the cost of the dike system prohibitive, it was decided that any further testing of this plan should be omitted.

Plan 13

55. This plan consisted of a dike approximately 4400 ft long, located 1200 ft east of the center line of New Castle Range at its upper end and 1600 ft east of the center line at the lower end, and extending from channel station 233+000 to station 237+300 (plate 6). The purpose of this plan was to direct more of the flood currents into the New Castle Range channel.

56. Only a photographic test, showing current directions with this plan installed, was run (photographs 33 and 34).

Plan 14

57. This plan consisted of a dike about 2600 ft long, extending from station 237+500 to station 240+000 (plate 6). The upstream end of the dike was 1200 ft west of the center line of the Finns Point Range, and the downstream end was located 1600 ft west of the center line. The purpose of this plan was to deflect into the main channel the flood currents normally flowing to the west of Pea Patch Island.

58. Only a photographic test was run. Photographs 35 and 36 show current directions with this plan installed in the model.

Plan 15

59. This plan consisted of a dike approximately 4000 ft long located west of the New Castle Range with the upstream end of the dike 1200 ft west of the channel center line (plate 6). At a point 1700 ft downstream the dike was 1400 ft west of the center line, and the downstream end of the dike was 2000 ft west of the center line of the New Castle Range channel. The dike extended from station 228+700 to station

232+600. The purpose of this plan was to direct the flood flow into the main channel.

60. Only a photographic test was made. Photographs 37 and 38 show current directions with this plan installed in the model.

Plan 16

61. This plan consisted of a dike 2000 ft in length, generally located 1000 ft west of the center line of New Castle Range and extending from station 230+500 to station 232+500 (plate 6). The dike was located at a slight angle with the ship channel and was designed to increase the velocities of flood currents in the problem area.

62. Only a photographic test of this plan was conducted. Photographs 39 and 40 show current directions with plan 16 installed in the model.

Plan 17

63. This plan involved the removal of the eastern half of Pea Patch Island (plates 7 and 8). It was proposed to dredge this area to conform to the hydrography as shown on plate 7, and it was assumed that the dredged hydrographic conditions in the affected area would be self-maintaining. Computations indicate that roughly 5,500,000 cu yd of material would be removed under this plan. It was proposed to deposit the excavated material on the remaining portion of the island and in the river west of Pea Patch Island dike within the boundaries shown on plate 8. It was estimated that the dredged material would fill the proposed disposal area, including the remaining portion of the island, to an elevation of +12 to +14 ft. The object of removing this portion

of the island was to bring the ebb flow into alignment with the existing channel below Pea Patch Island. Under existing conditions the eastern end of the island, and particularly the wharf extending toward the channel, deflects the ebb flow away from the island, causing it to cross the channel in that vicinity at a sharp angle.

64. The shoaling index obtained for this test was 0.90 (table 1), indicating that the plan would reduce slightly the present rate of shoaling within the problem area. All of the reduction occurred in section 3, there being a slight increase in the rate of shoaling in section 1. There were material reductions in both ebb and flood velocities at station 223+500. (See plate 18 for tide and velocity measurements.) These reductions were due to the considerable increase in cross-sectional area of the channel at this point. There was no change in velocity at station 239+000. The direction of ebb currents closely followed the alignment of the ship channel through the problem area; however, the flood currents crossed the channel between stations 235+000 and 230+000 and again at station 226+000 (photographs 41 and 42).

Plan 18

65. This plan involved the removal of the portion of Pea Patch Island east of the line shown on plates 7 and 8. It was proposed to dredge the area east of this line to the hydrography shown on plate 7. The 700,000 cu yd of material estimated to be dredged under this plan was to be deposited in the angle between the upper western end of the island and the dike, as shown on plate 8. This plan was designed to improve the ebb flow conditions in the problem reach of the channel.

66. The shoaling index obtained for the test of this plan was

0.85 (table 1), indicating that this plan would reduce to some extent the present rate of shoaling in the problem area. Due to the enlarged cross section of the channel, there was some decrease in the flood and ebb velocities at station 223+500, although not so great as was observed for plan 17. There was no appreciable change in flood or ebb velocities at station 239+000. (See plate 19 for tide and velocity measurements.) The direction of ebb flow was in alignment with the dredged channel, and that of flood flow was more nearly in alignment with the channel than for plan 17 (photographs 43 and 44).

General conditions for plans 19, 20, and 21

67. In testing plans 19, 20, and 21 it was assumed that the depths for the full width of the realigned channel were 40 ft wherever the existing soundings indicated depths of less than 40 ft, and that the abandoned portion of the channel would eventually shoal to natural depths conforming to the adjoining portions of the river bed.

Plan 19

68. This plan consisted of a 1.67-degree change in alignment of the New Castle Range beginning at station 221+000 (plates 7 and 8). The lower end of the relocated reach connected with the present Finns Point Range extended. This plan was designed to shift the channel away from the area of apparent excessive shoaling on the western edge of the present channel and also to bring the channel into closer alignment with the direction of ebb currents.

69. The shoaling index obtained for the test of this plan was 1.05 (table 1), indicating that the plan would increase very slightly

the present rate of shoaling within the problem area. The plan caused no appreciable change in current velocities at stations 223+500 and 239+000. (See plate 20 for tide and velocity measurements.) The directions of flood and ebb currents were approximately the same as those observed during the base test (photographs 45 and 46).

Plan 20

70. This plan consisted of the realigned channel of plan 19 (paragraph 68) and a training dike located 1200 ft west of and parallel to the center line of the realigned section of New Castle Range, beginning opposite station 227+000 and extending downstream a distance of 5000 ft (plate 8). The purpose of this dike was to eliminate, to some extent, the interference with the ebb flow in the main channel by that from the secondary channel.

71. The shoaling index obtained from the test of this plan was 1.13 (table 1), indicating that the plan would slightly increase the present rate of shoaling in the problem area. There were slight decreases in ebb velocities at stations 223+500 and 239+000 with no appreciable change in flood velocities. (See plate 21 for tide and velocity measurements.) The directions of flood and ebb currents were about the same as observed during the base test, except for slight local effects in the vicinity of the training wall (photographs 47 and 48).

Plan 21

72. This plan consisted of the realigned channel of plan 19 (paragraph 68) and a training dike extending from station 224+500 to station 228+100 (plate 8). The upper and lower ends of the dike were, respectively,

1650 and 1400 ft east of the center line of the realigned section of New Castle Range. This plan was designed to deflect the ebb currents, normally flowing over the shoal area east of the channel, into alignment with the dredged channel.

73. The shoaling index obtained for this test was 0.86 (table 1), indicating that this plan would decrease to some extent the present rate of shoaling in the problem area. The greater portion of this decrease occurred in section 1, the section of the channel most affected by the training wall. Ebb velocities at station 223+500 were reduced slightly with no change in flood velocities. There was little change in flood or ebb velocities at station 239+000. (See plate 22 for tide and velocity measurements.) The direction of flood currents was not materially affected by this plan; however, the ebb currents followed more closely the alignment of the dredged channel (photographs 49 and 50).

Plan 22

74. This plan consisted of a training dike parallel to and 1300 ft west of the center line of the New Castle Range, beginning at station 215+000 and extending upstream a distance of 3600 ft (plate 8). From this point, the dike turned eastward 23 degrees and continued along this line a distance of 2500 ft until it met the existing Pea Patch Island dike. The hydrography simulated in the model during this test was the same as that of the base test. The purpose of this dike was to deflect a portion of the ebb flow away from the shoal area west of and immediately above Pea Patch Island into alignment with the dredged channel.

75. The shoaling index obtained for this test was 0.97 (table 1), indicating that the plan would not materially affect the present rate of

shoaling within the problem area. It may be noted that shoaling in section 2 was increased. The plan caused no appreciable changes in flood and ebb velocities at stations 223+500 and 239+000. (See plate 23 for tide and velocity measurements.) The directions of flood and ebb currents were not improved over those observed during the base test (photographs 51 and 52).

PART V: DISCUSSION OF RESULTS

76. Of the twenty-two proposed plans of improvement tested in the New Castle-Finns Point Ranges model, the four most effective were plans 1, 4, 18, and 21, which effected reductions in total shoaling of 17, 15, 15, and 14 per cent, respectively, in the model tests. These four plans may, therefore, be considered as being about equally effective in reducing shoaling in the problem area.

77. However, as has already been pointed out, the model reproduction of volumes and distributions of shoaling under identical test conditions is considered to be accurate only to within about 10 per cent. It is the opinion of the Experiment Station, therefore, that none of these four proposed plans could be expected to effect a very great percentile reduction in shoaling, but that any of them would reduce shoaling by 5 per cent as a minimum.

78. A study of the effects of plans 1, 4, 18, and 21 upon currents in the navigation channel shows that any of these plans would improve to some extent the alignment of flood and ebb currents in the vicinity of Pea Patch Island, and that plan 21 would effect the best over-all alignment of currents with the channel. However, it is not believed that such current realignments would be of significant value, except as reflected in the shoaling reductions discussed above.

79. In view of the fact that none of the plans tested in the model produced any very outstanding improvements, the Experiment Station does not recommend that any plan be installed in the prototype.

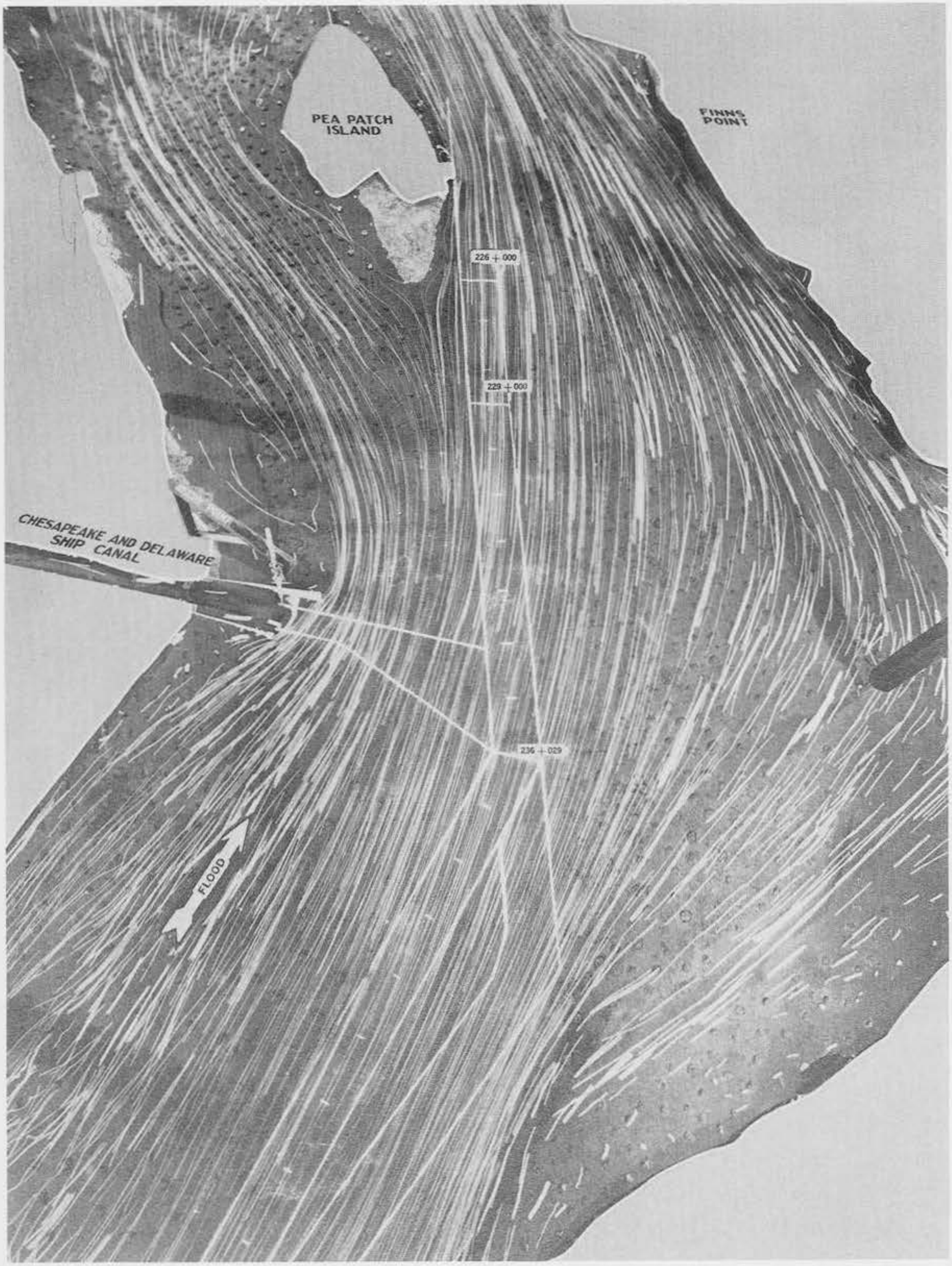
TABLE 1

Results of Shoaling Tests

Test	Shoaling in Section 1		Shoaling in Section 2		Shoaling in Section 3		Total Shoaling (CC) in Sections 1, 2, & 3	Shoaling Index	Shoaling (CC) in Other Sections		
	(CC)	Per Cent Total	(CC)	Per Cent Total	(CC)	Per Cent Total			Section 4	Section 5	Section 6
Base	465	18.0	1391	52.0	787	30.0	2643	1.00	215	589	61
Plan 1	437	20.0	1094	50.0	660	30.0	2191	0.83	204	520	33
Plan 2A	555	21.0	1427	54.5	611	24.0	2593	0.98	193	472	33
Plan 2B	423	17.0	1351	57.0	621	26.0	2395	0.91	197	431	62
Plan 3	708	30.0	1200	50.5	455	19.5	2363	0.89	383	300	46
Plan 4	425	18.5	1206	54.0	615	27.5	2246	0.85	338	404	34
Plan 5	867	28.0	1469	47.5	741	24.5	3077	1.16	375	385	63
Plan 6	255	11.0	1274	55.5	772	33.0	2301	0.87	369	550	47
Plan 7	682	26.0	1212	46.5	726	27.5	2620	0.99	391	495	68
Plan 8	875	24.5	1821	51.5	836	23.5	3532	1.34	467	552	70
Plan 17	601	25.0	1114	47.0	660	28.0	2375	0.90	211	466	51
Plan 18	357	16.5	1257	56.0	628	27.5	2242	0.85	215	461	60
Plan 19	459	16.5	1607	57.5	718	26.0	2784	1.05	281	544	66
Plan 20	598	20.0	1572	52.5	806	27.5	2976	1.13	232	552	79
Plan 21	216	9.5	1320	58.5	725	32.0	2261	0.86	292	410	62
Plan 22	337	13.0	1500	58.5	715	28.5	2552	0.97	233	554	82

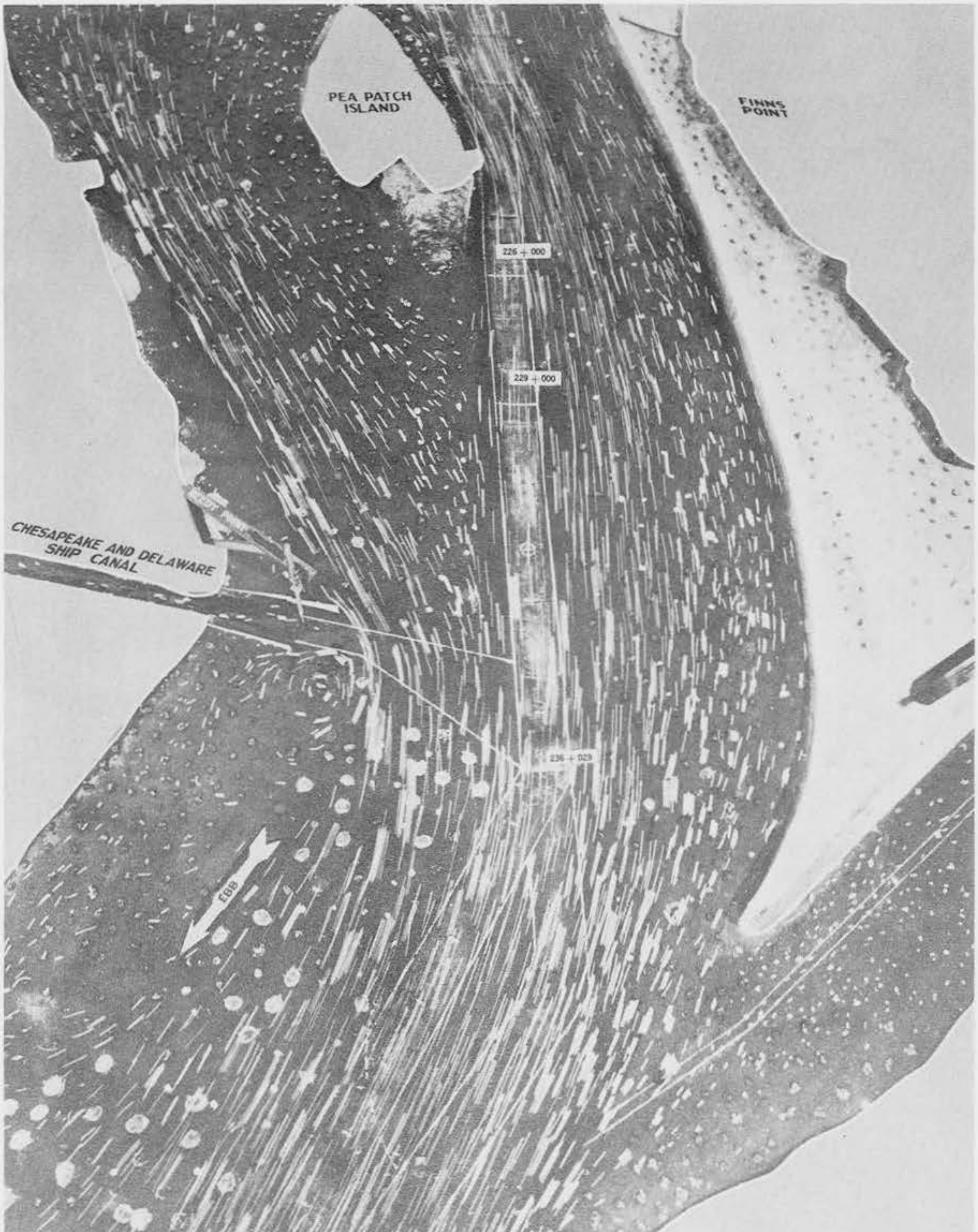
PHOTOGRAPHS

Base Test, Strength of Ebb

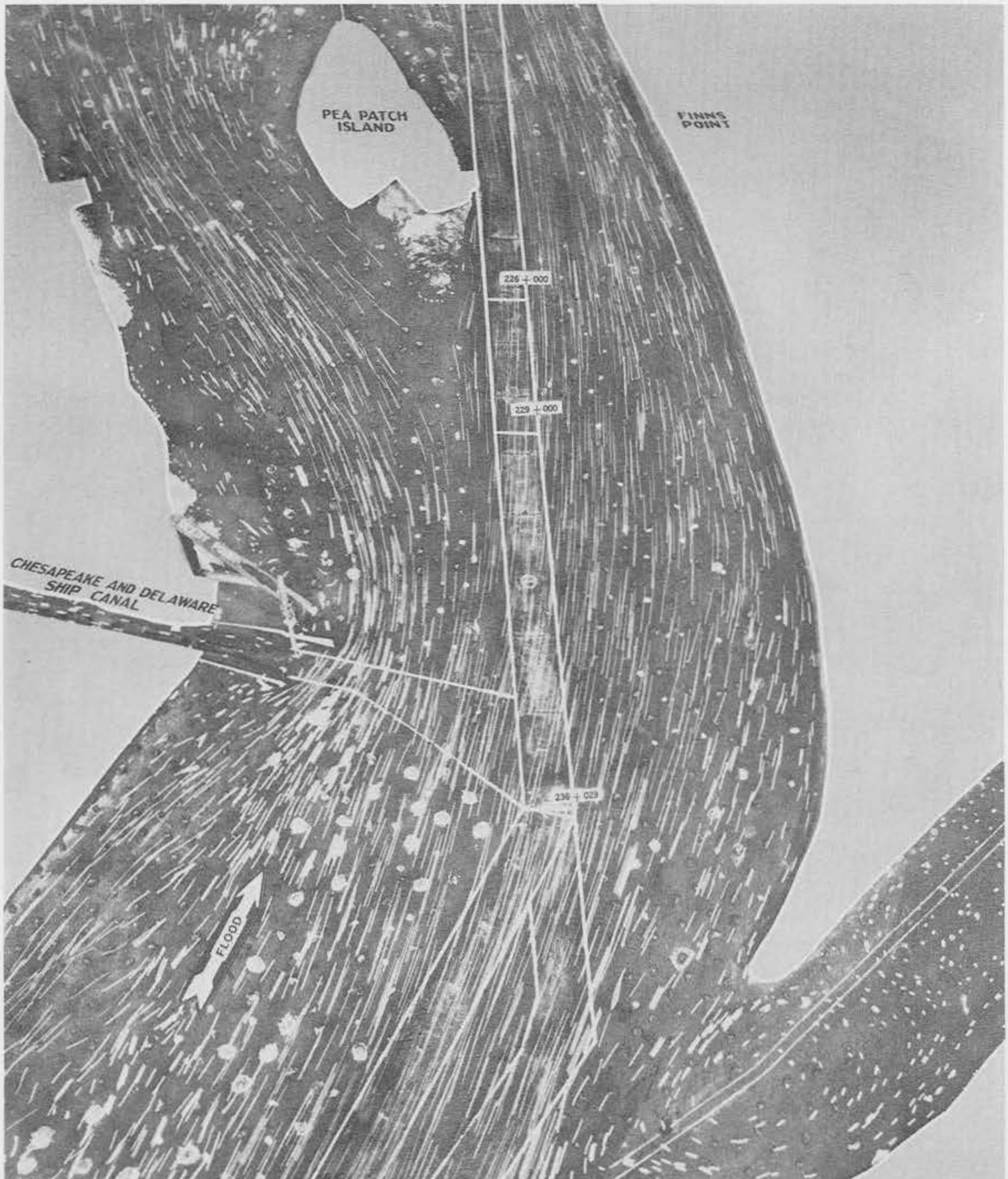


Base Test, Strength of Flood

Photograph 2

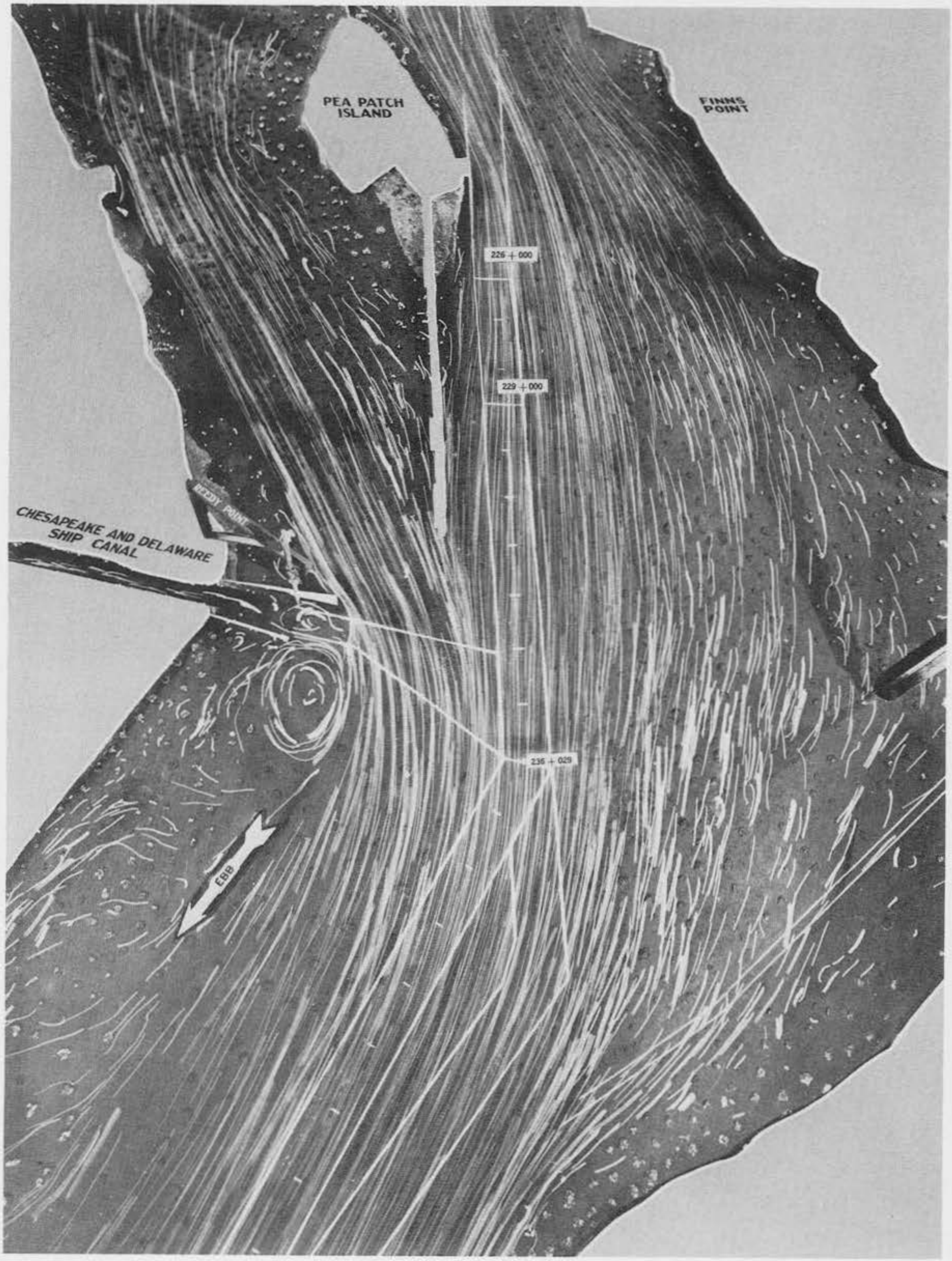


Plan 1, Strength of Ebb

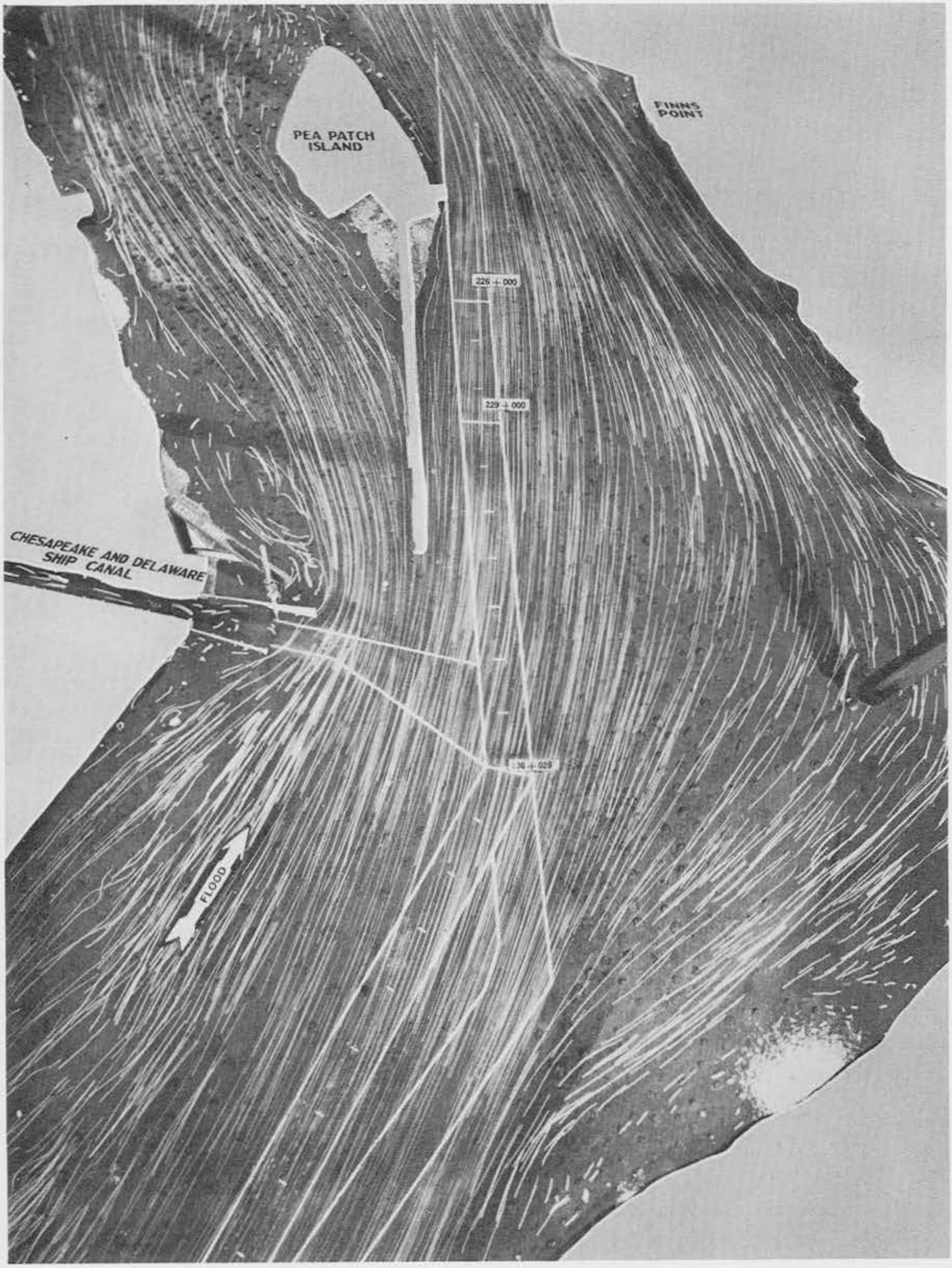


Plan 1, Strength of Flood

Photograph 4



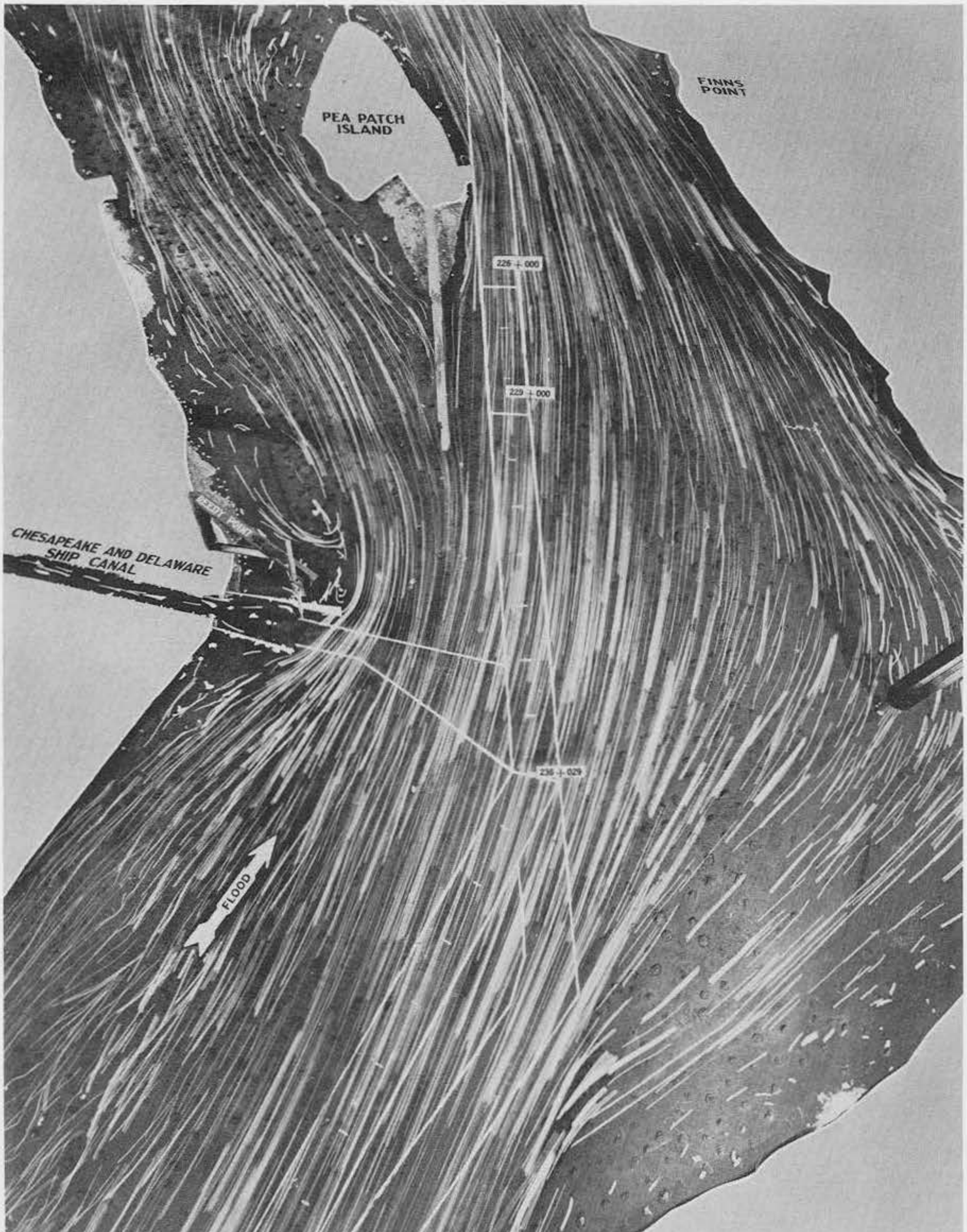
Plan 2A, Strength of Ebb



Plan 2A, Strength of Flood

Photograph 6

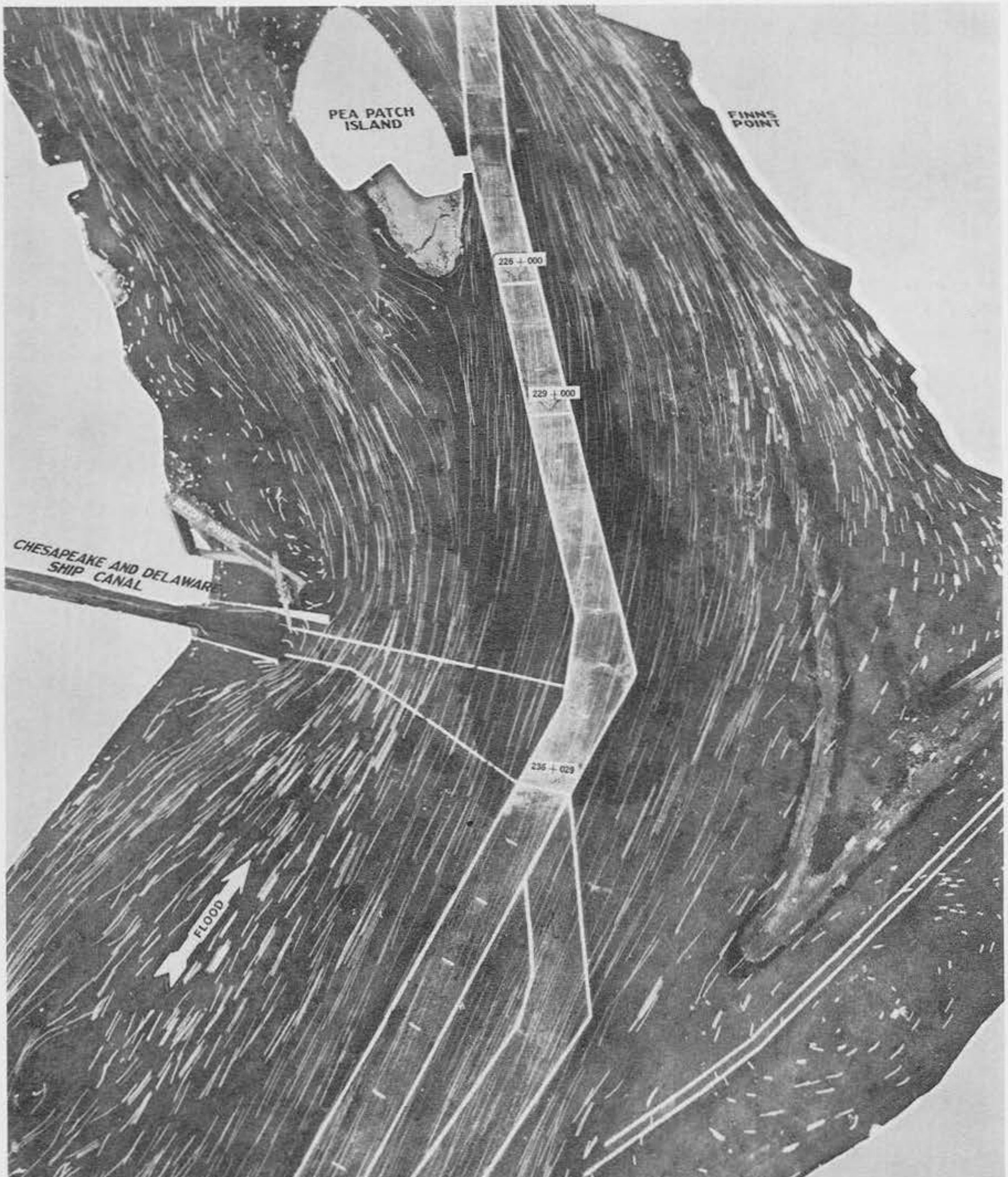
Plan 2B, Strength of Ebb



Plan 2B, Strength of Flood

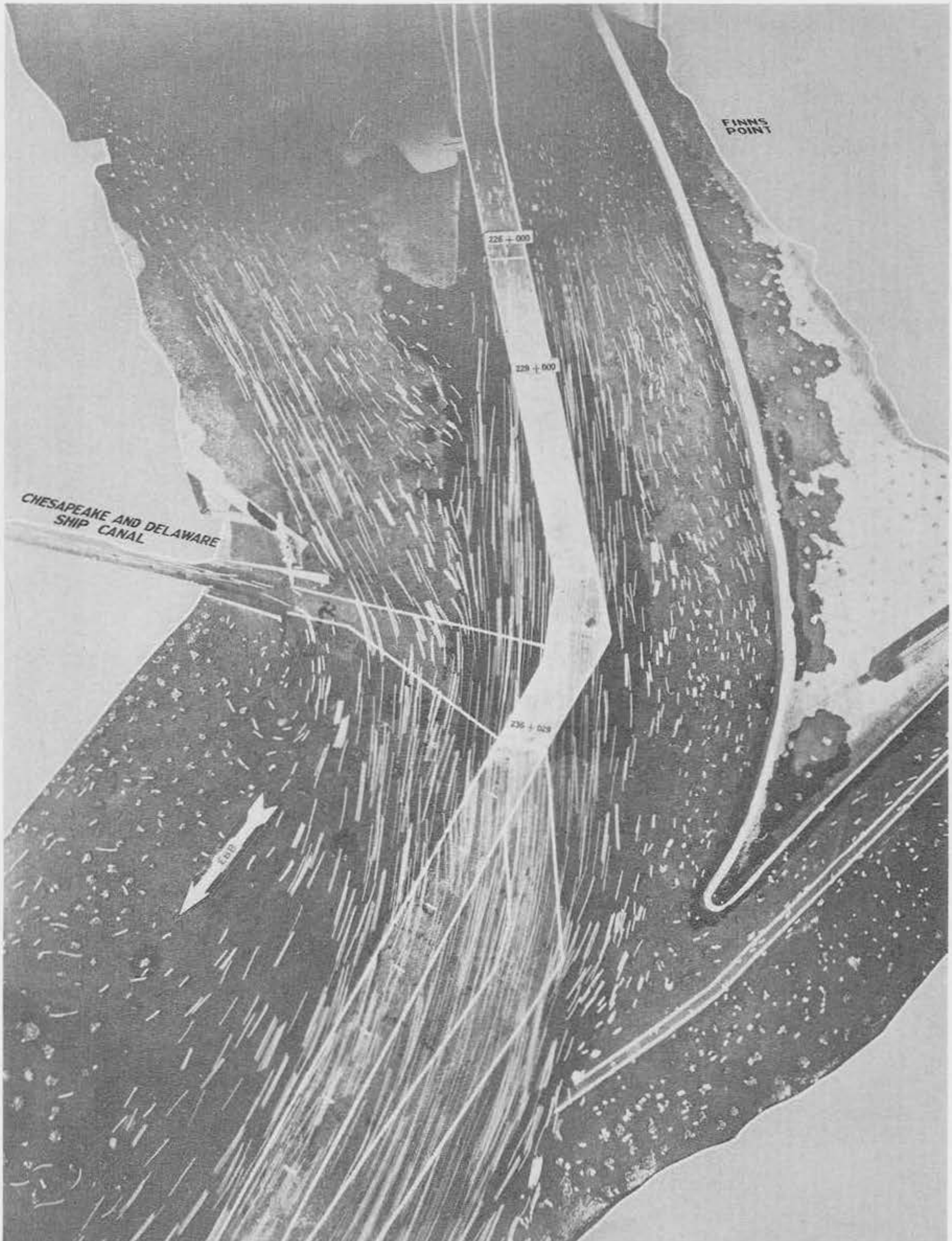
Photograph 8

Plan 3, Strength of Ebb



Plan 3, Strength of Flood

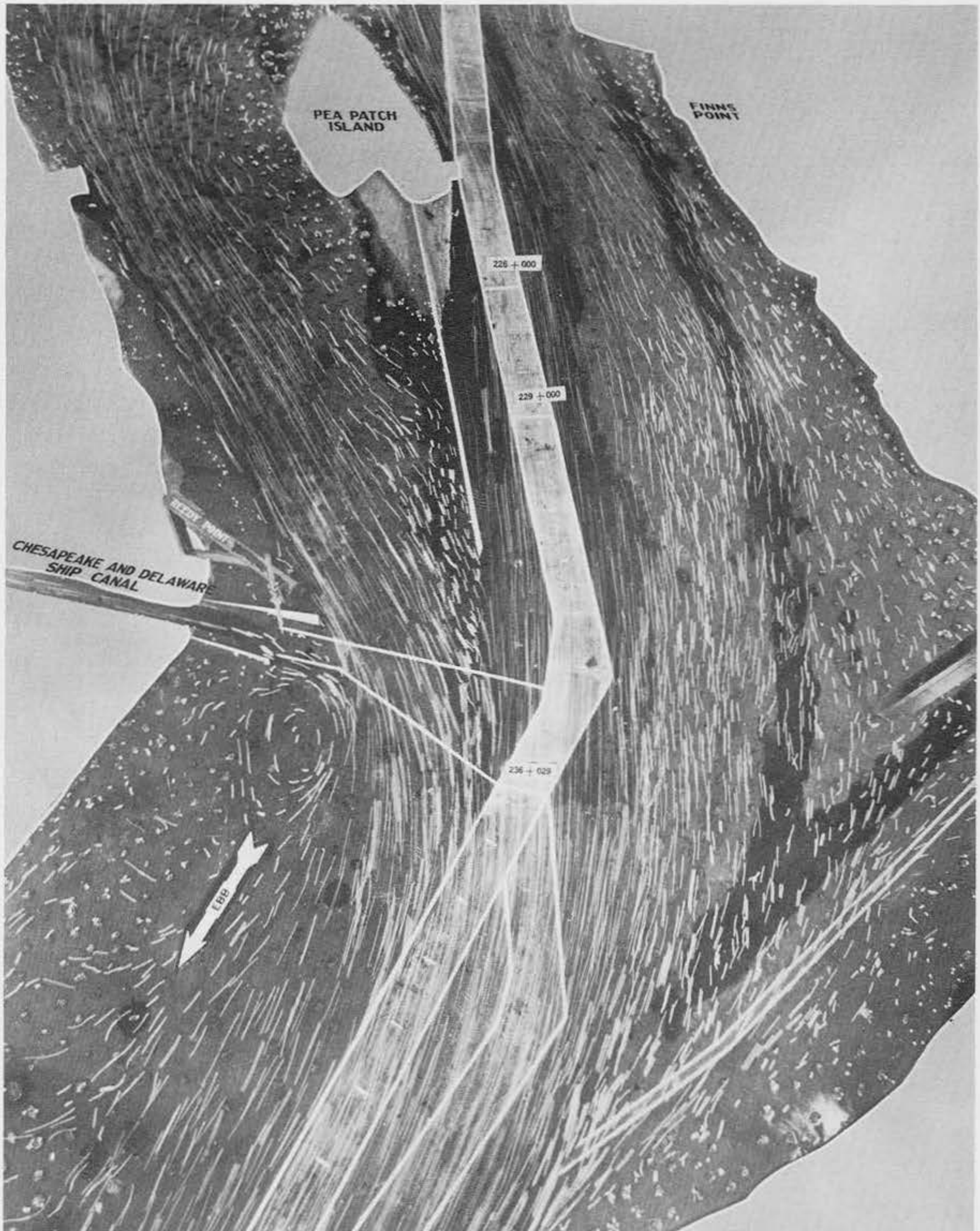
Photograph 10



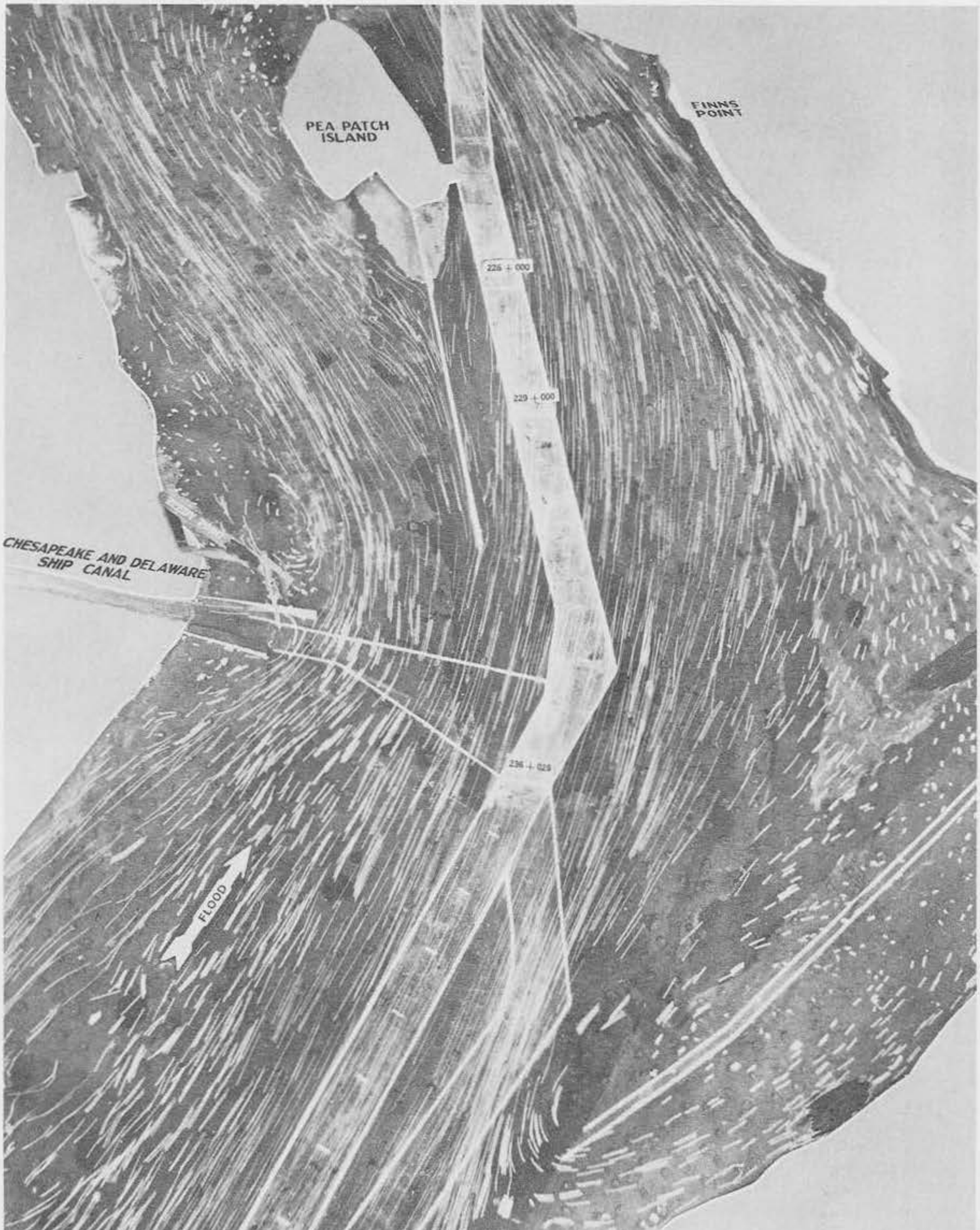
Plan 4, Strength of Ebb

Plan 4, Strength of FLood

Photograph 12

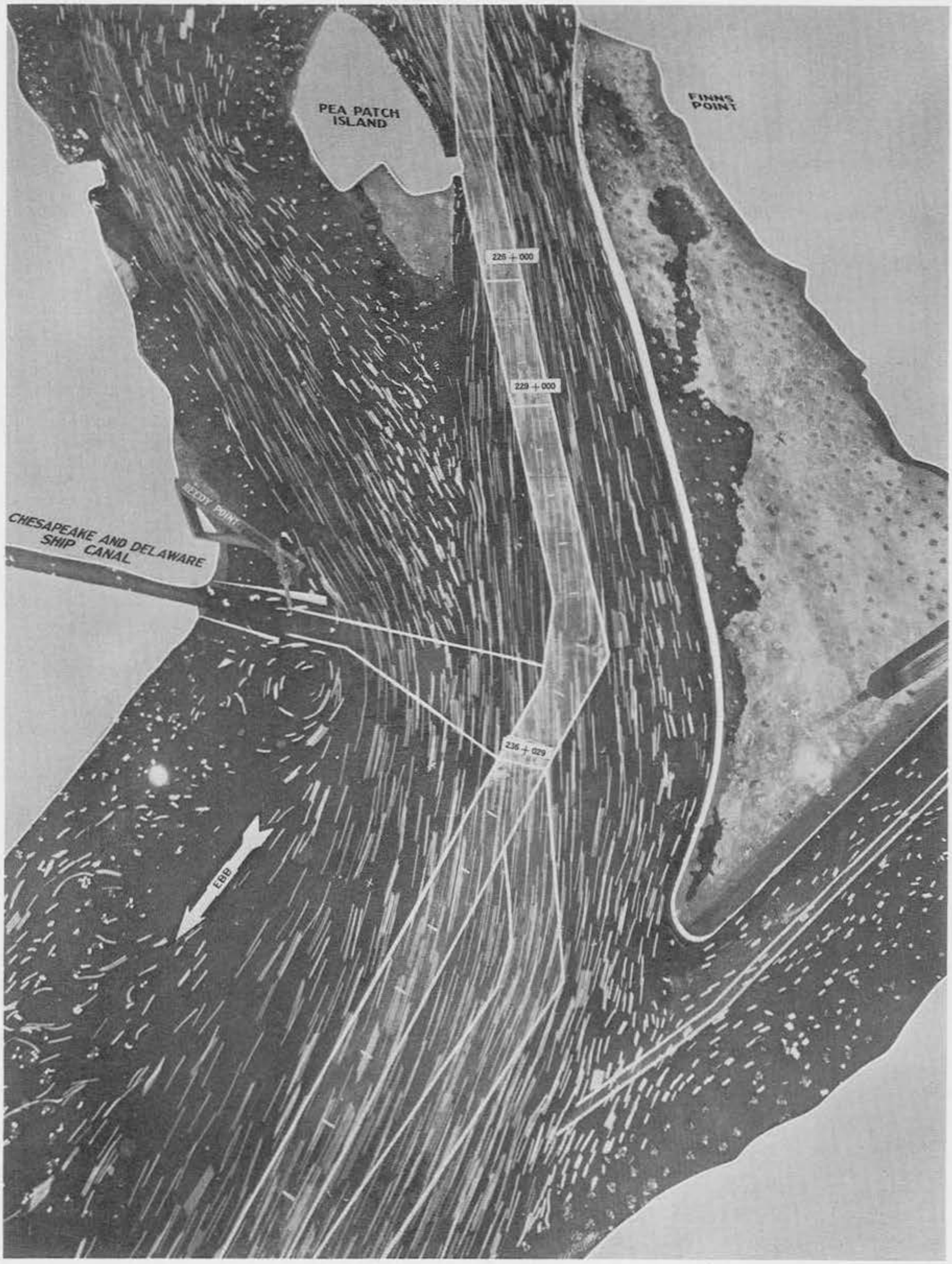


Plan 5, Strength of Ebb

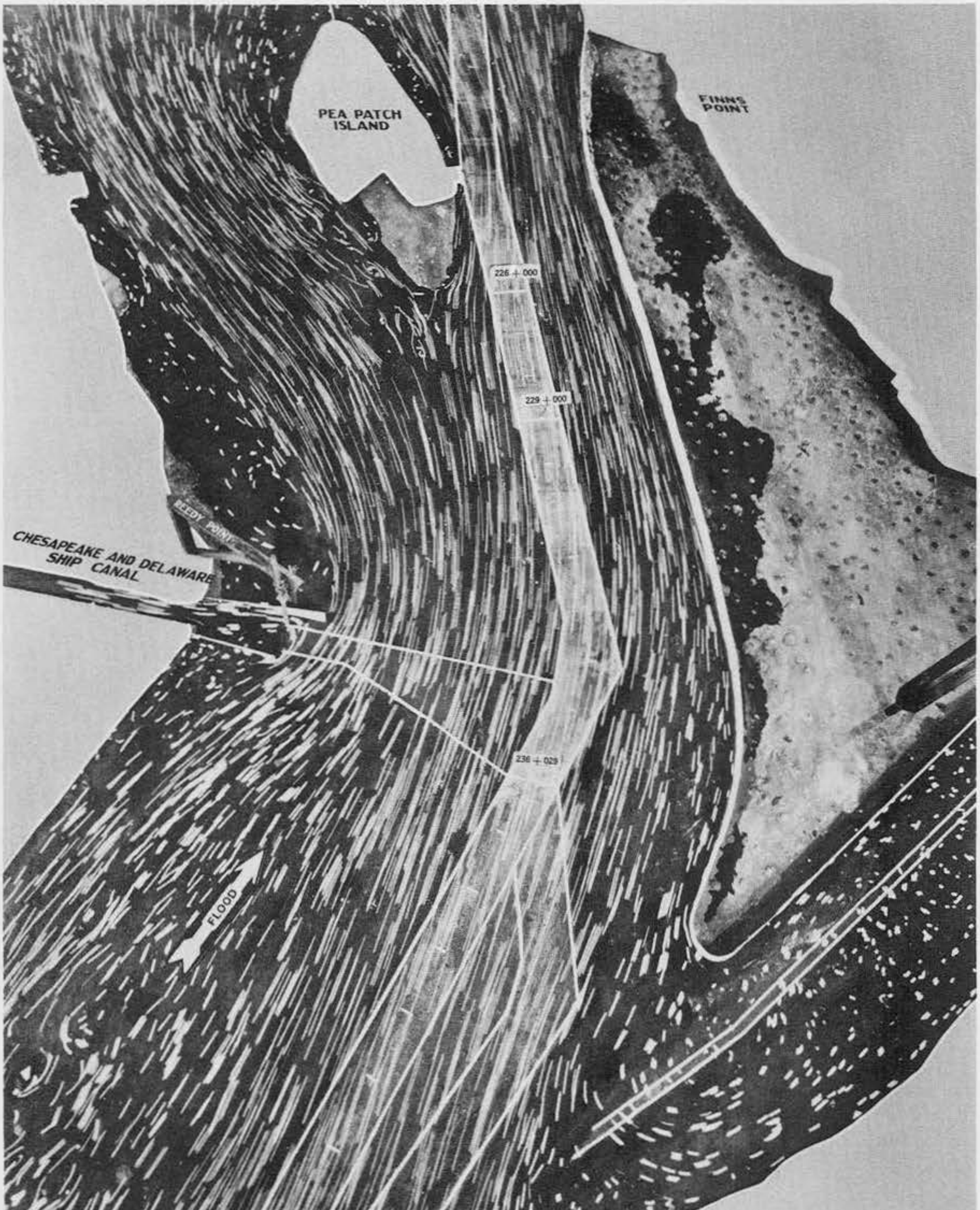


Plan 5, Strength of Flood

Photograph 14



Plan 6, Strength of Ebb



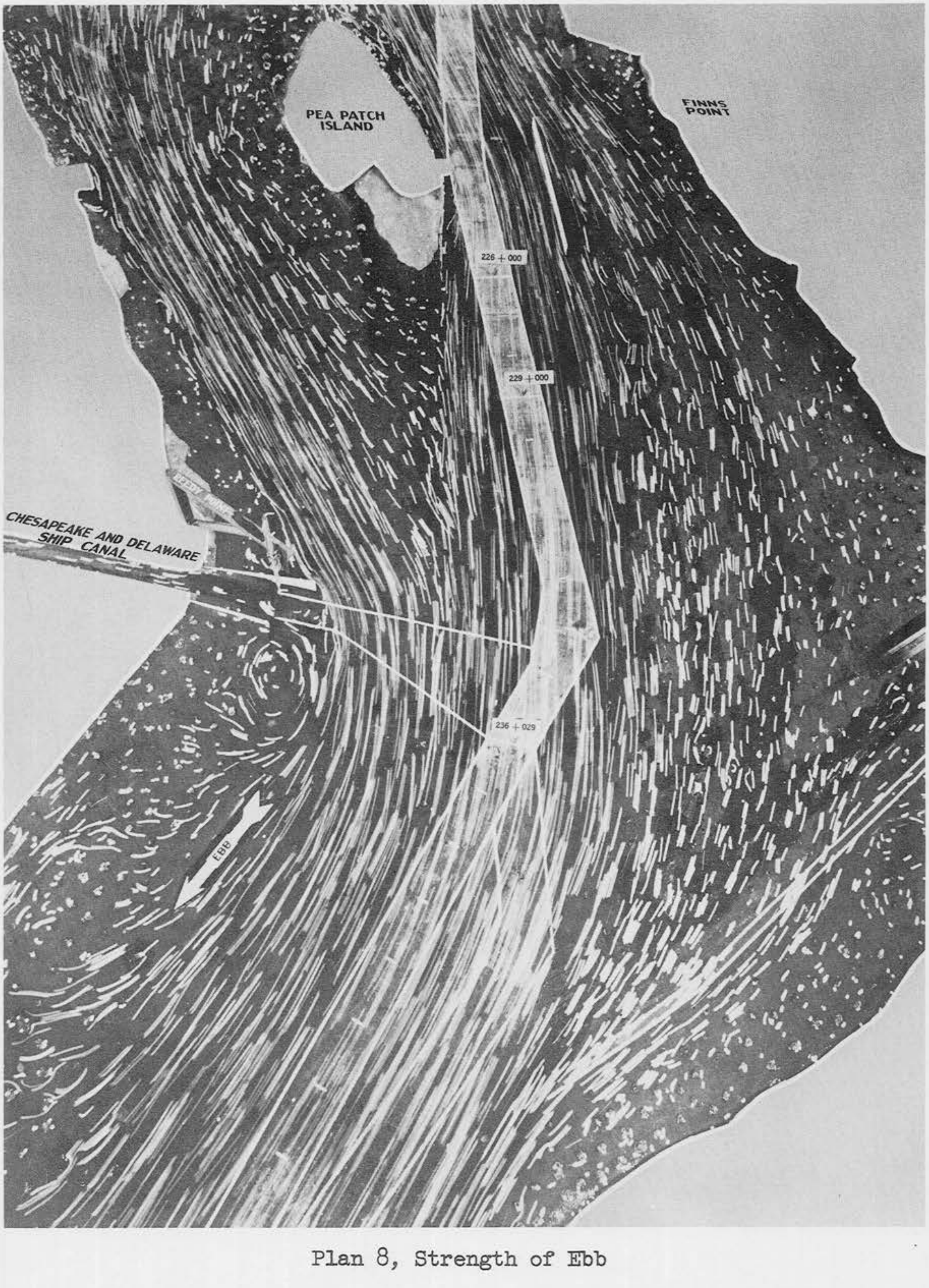
Plan 6, Strength of Flood

Photograph 16

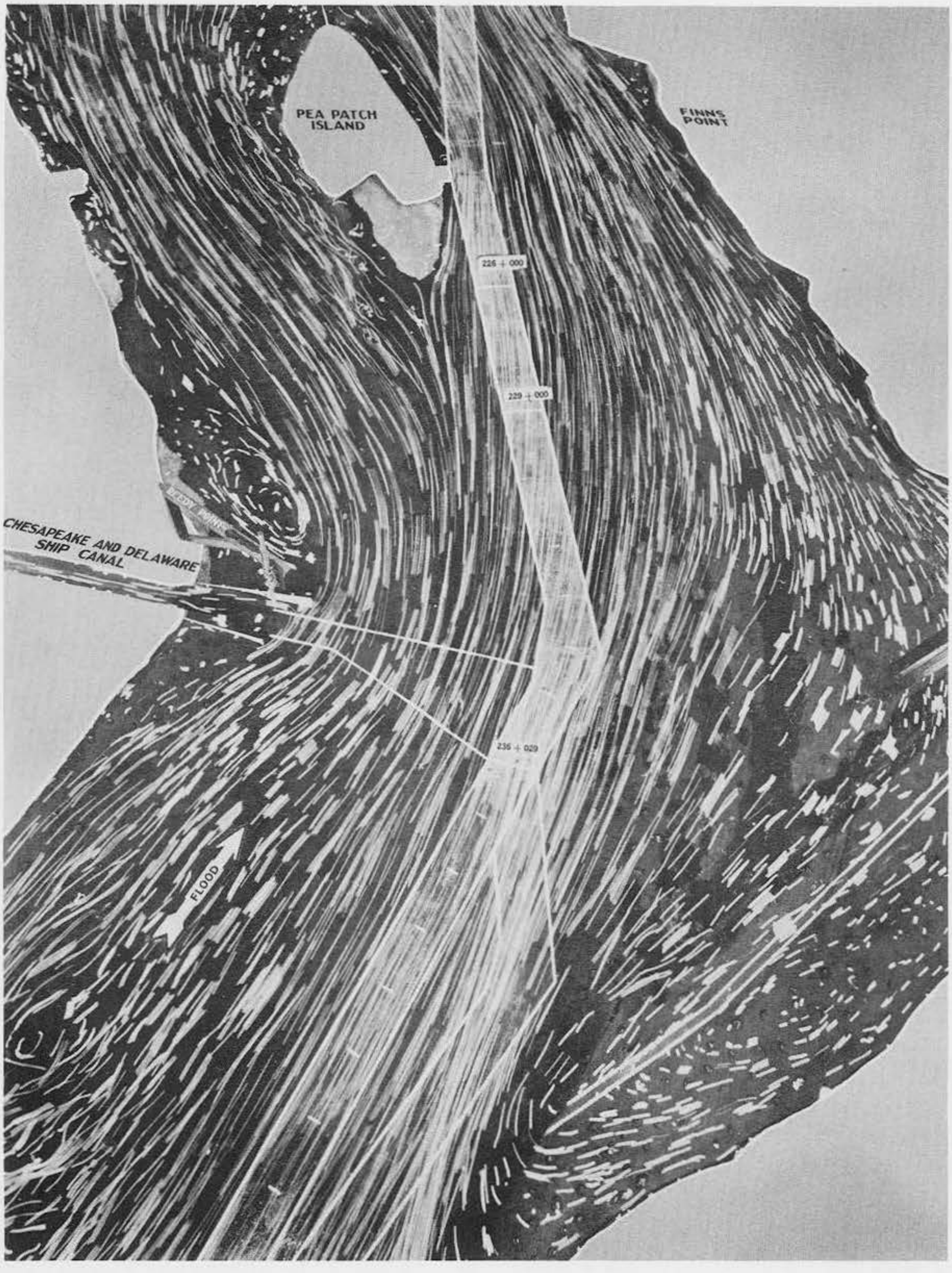
Plan 7, Strength of Ebb

Plan 7, Strength of Flood

Photograph 18

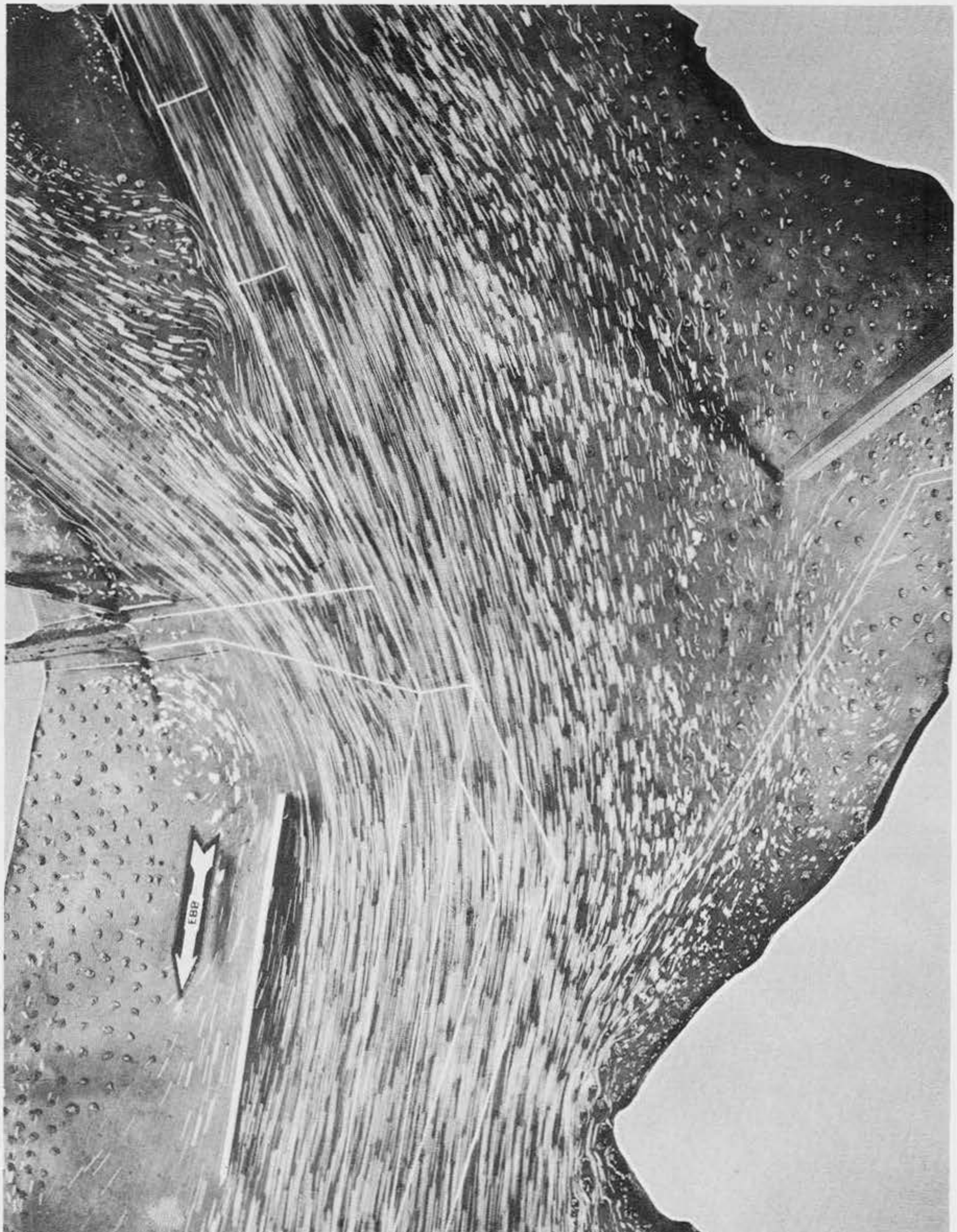


Plan 8, Strength of Ebb

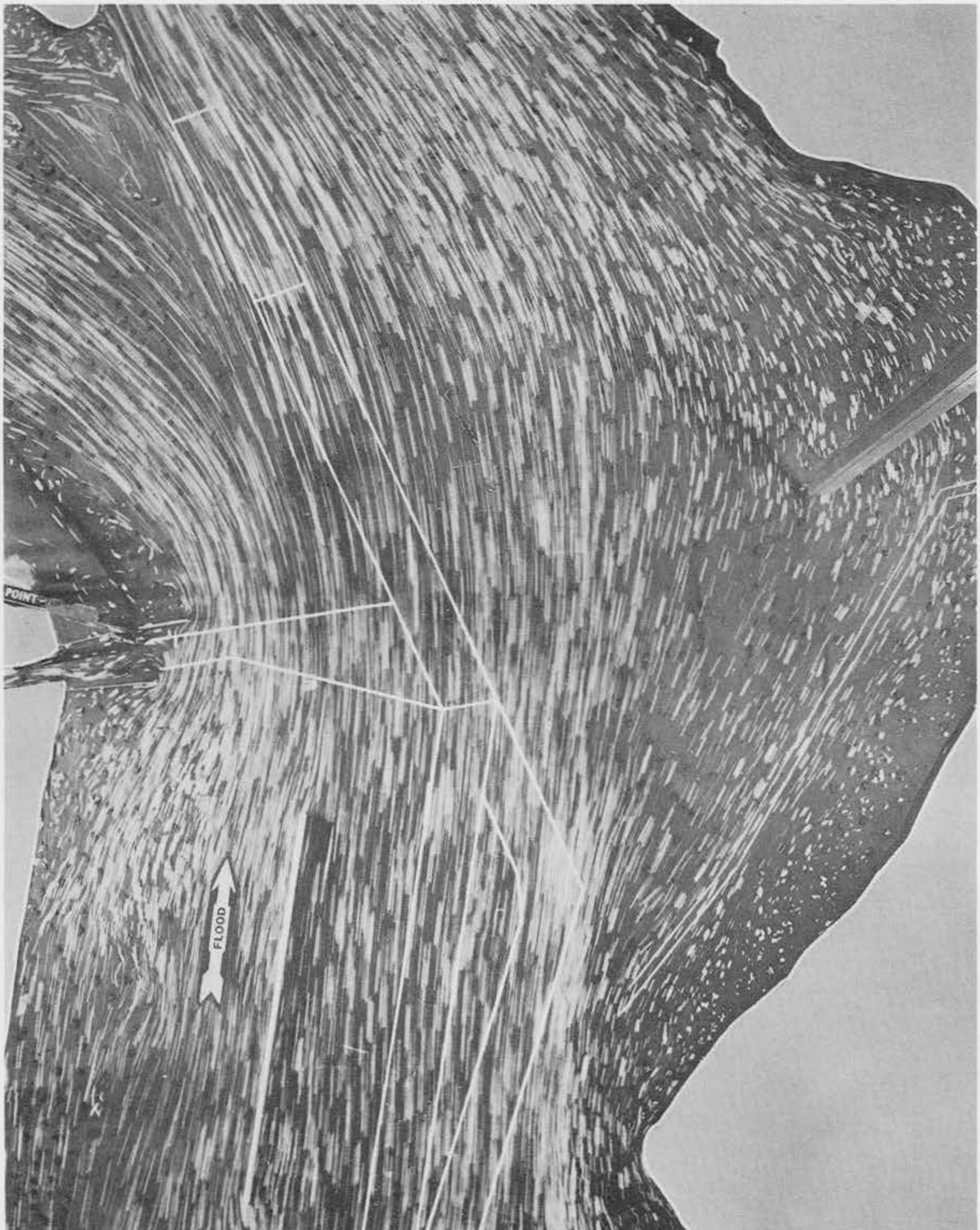


Plan 8, Strength of Flood

Photograph 20

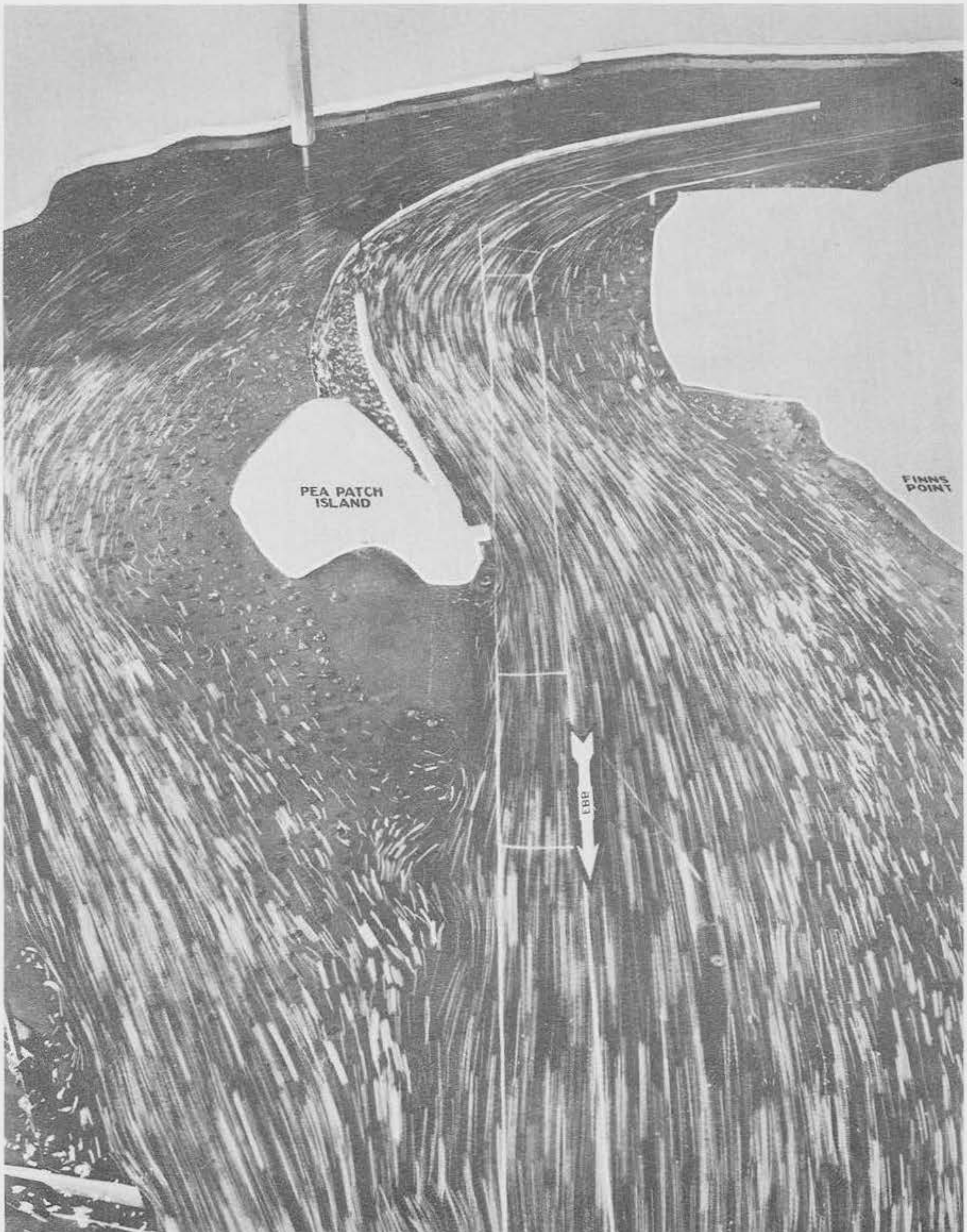


Plan 9, Strength of Ebb



Plan 9, Strength of Flood

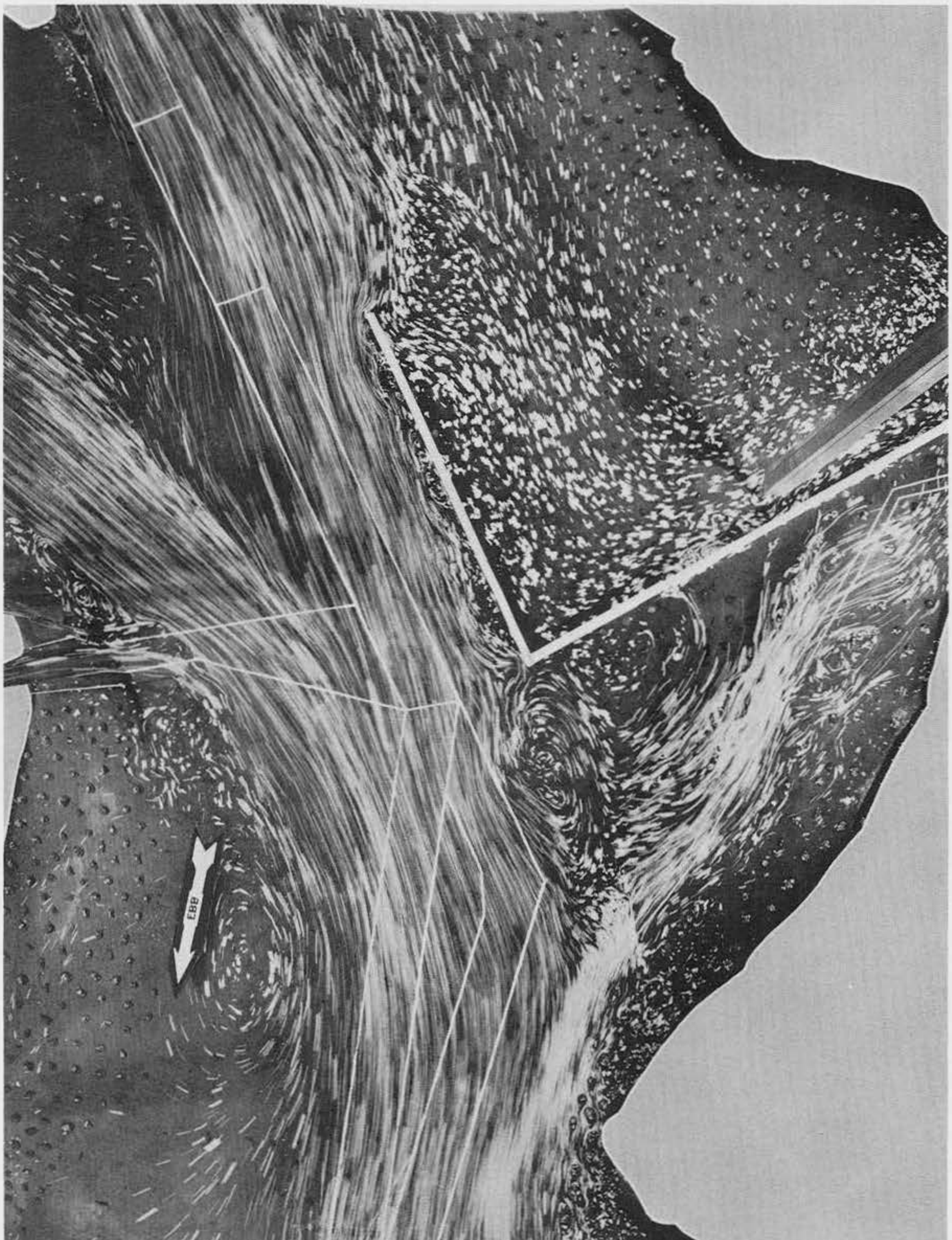
Photograph 22



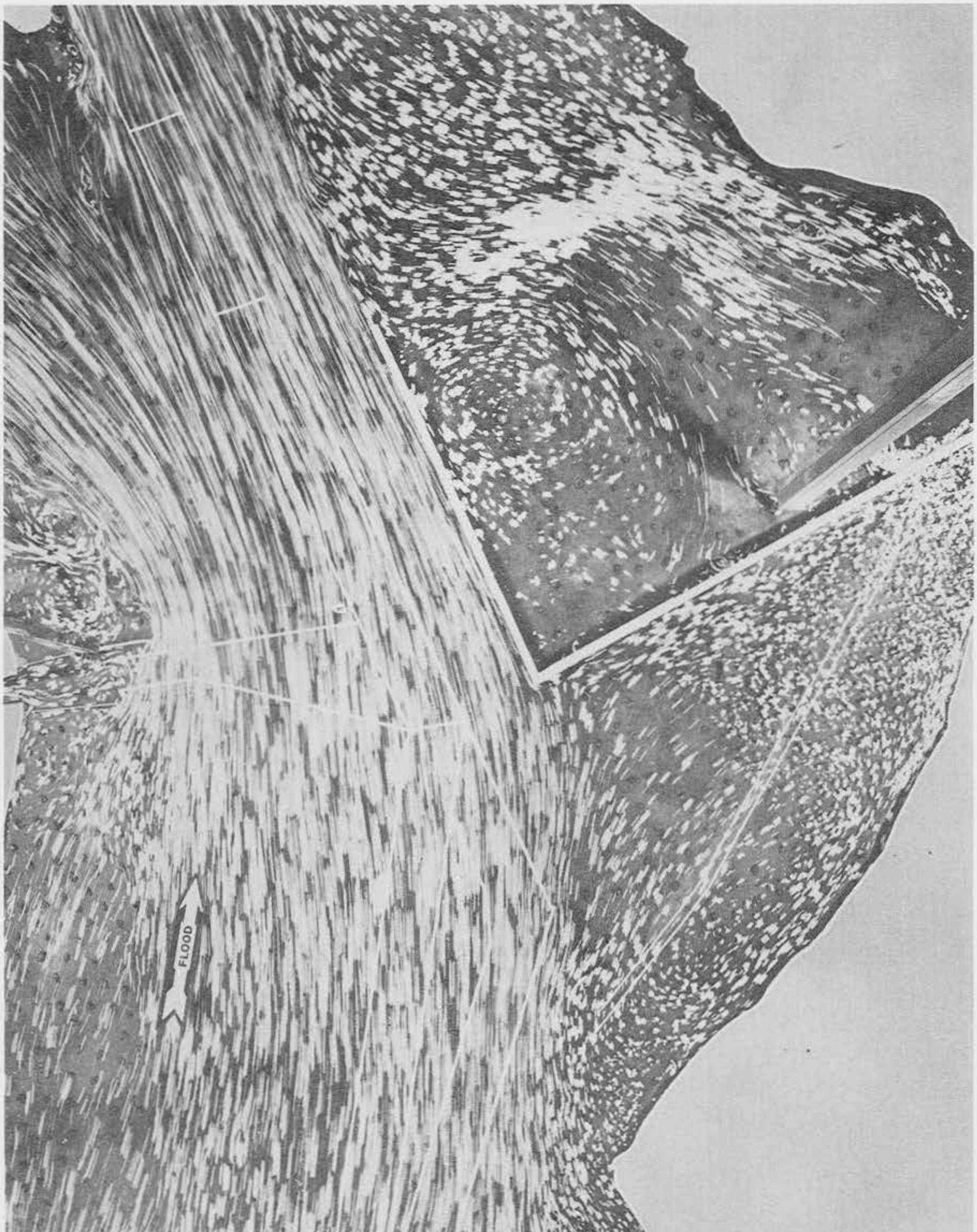
Plan 11, Strength of Ebb

Plan 11, Strength of Flood

Photograph 24



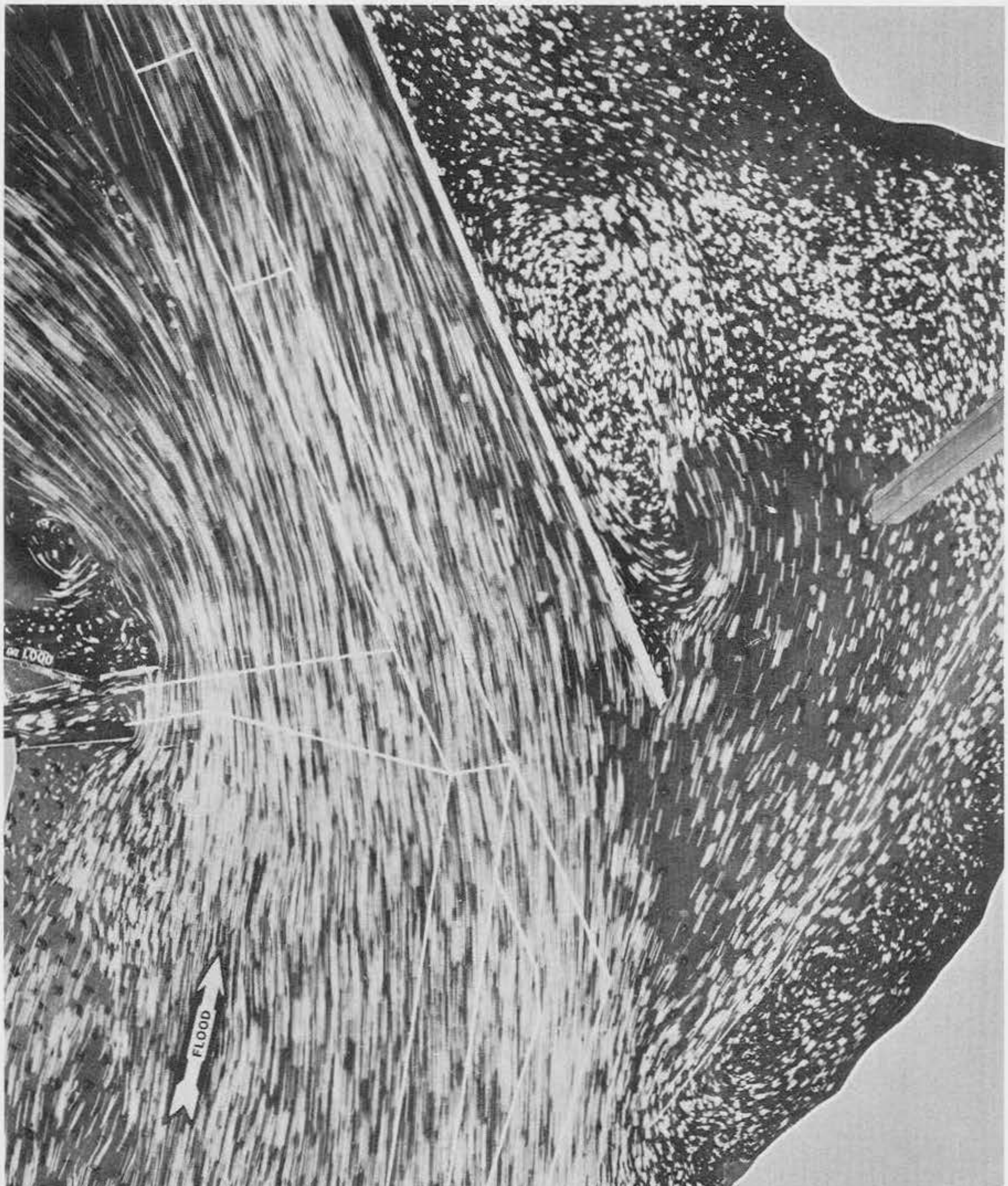
Plan 11A, Strength of Ebb



Plan 11A, Strength of Flood

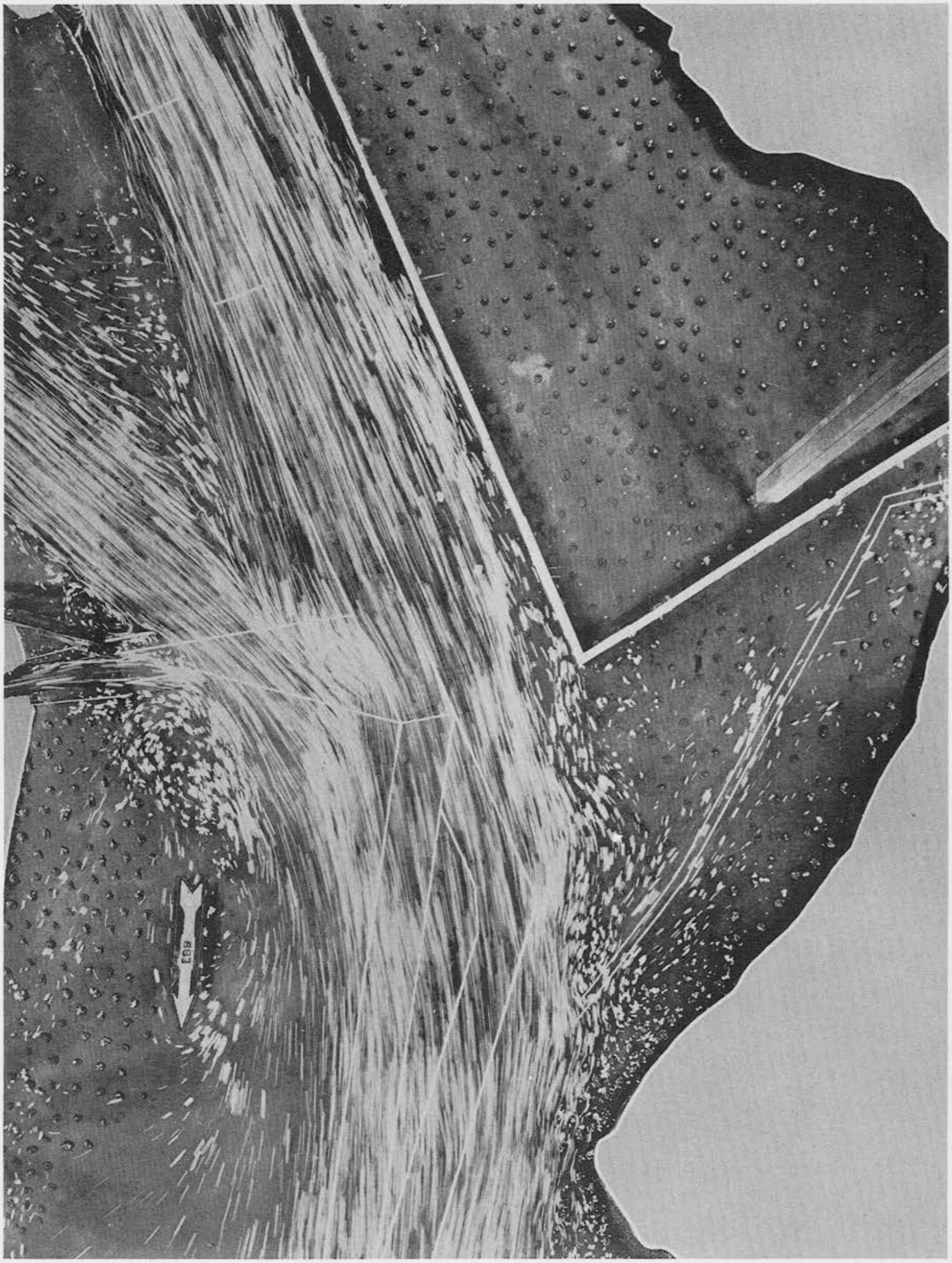
Photograph 26

Plan 11B, Strength of Ebb

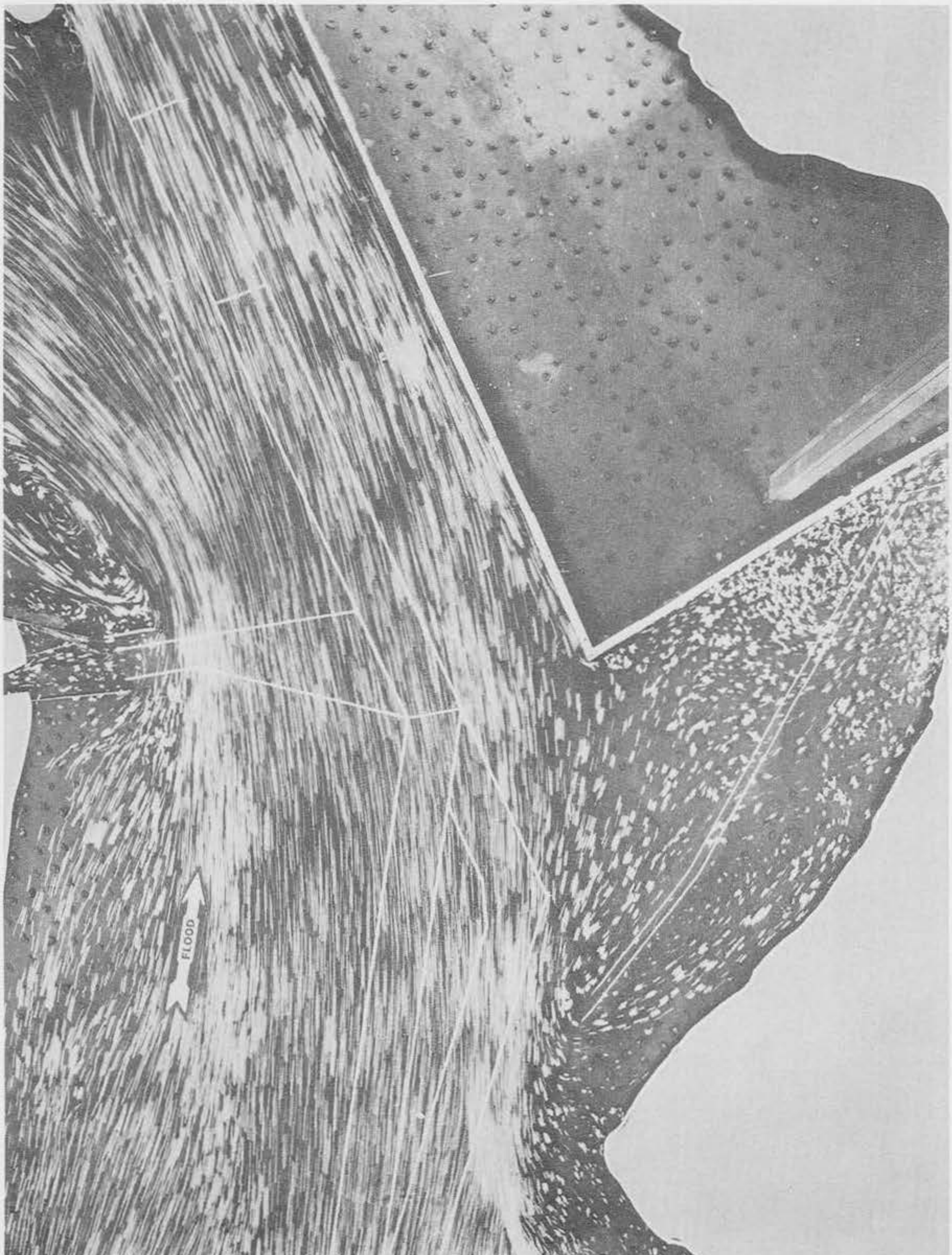


Plan 11B, Strength of Flood

Photograph 28

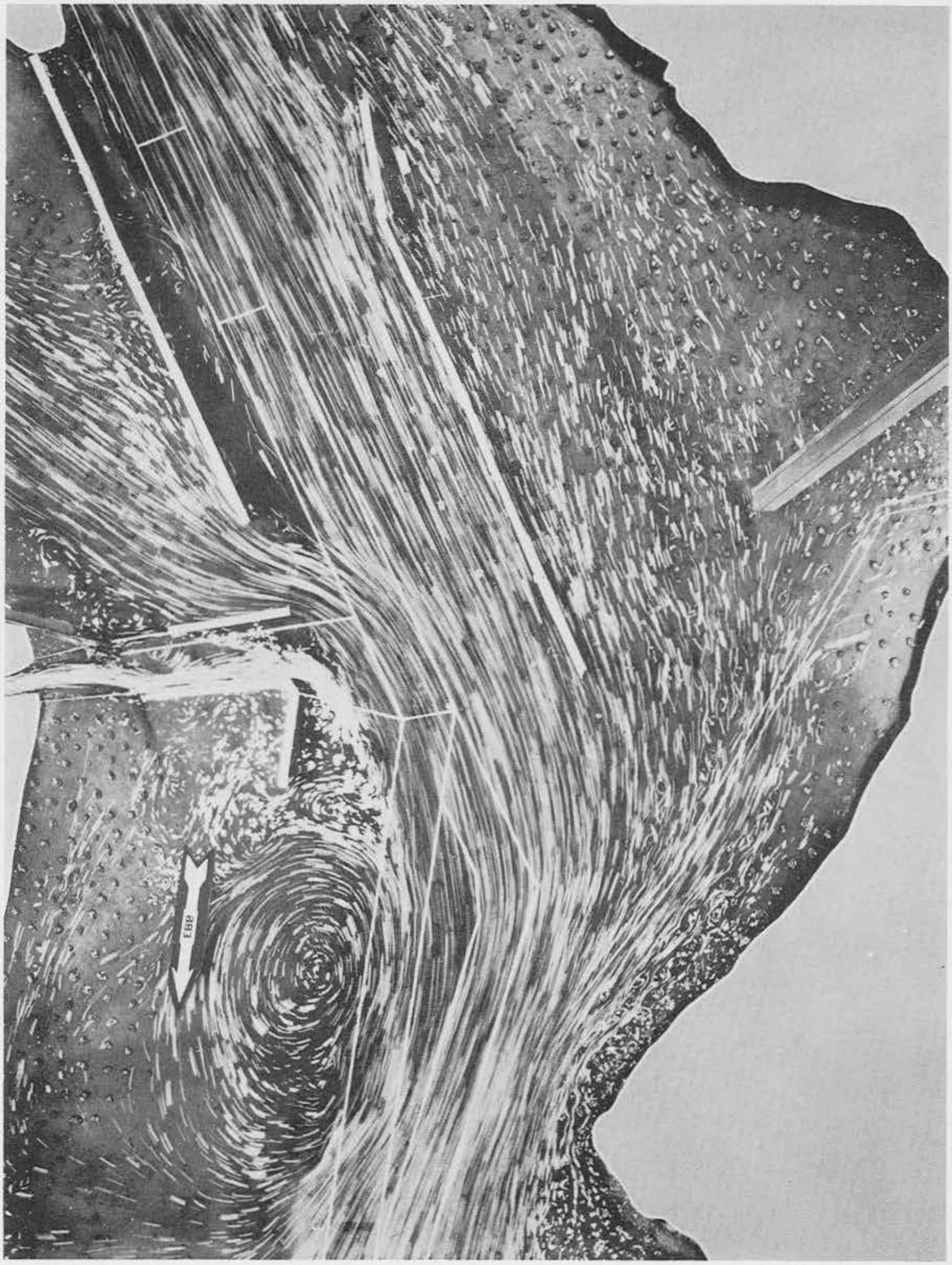


Plan 11C, Strength of Ebb

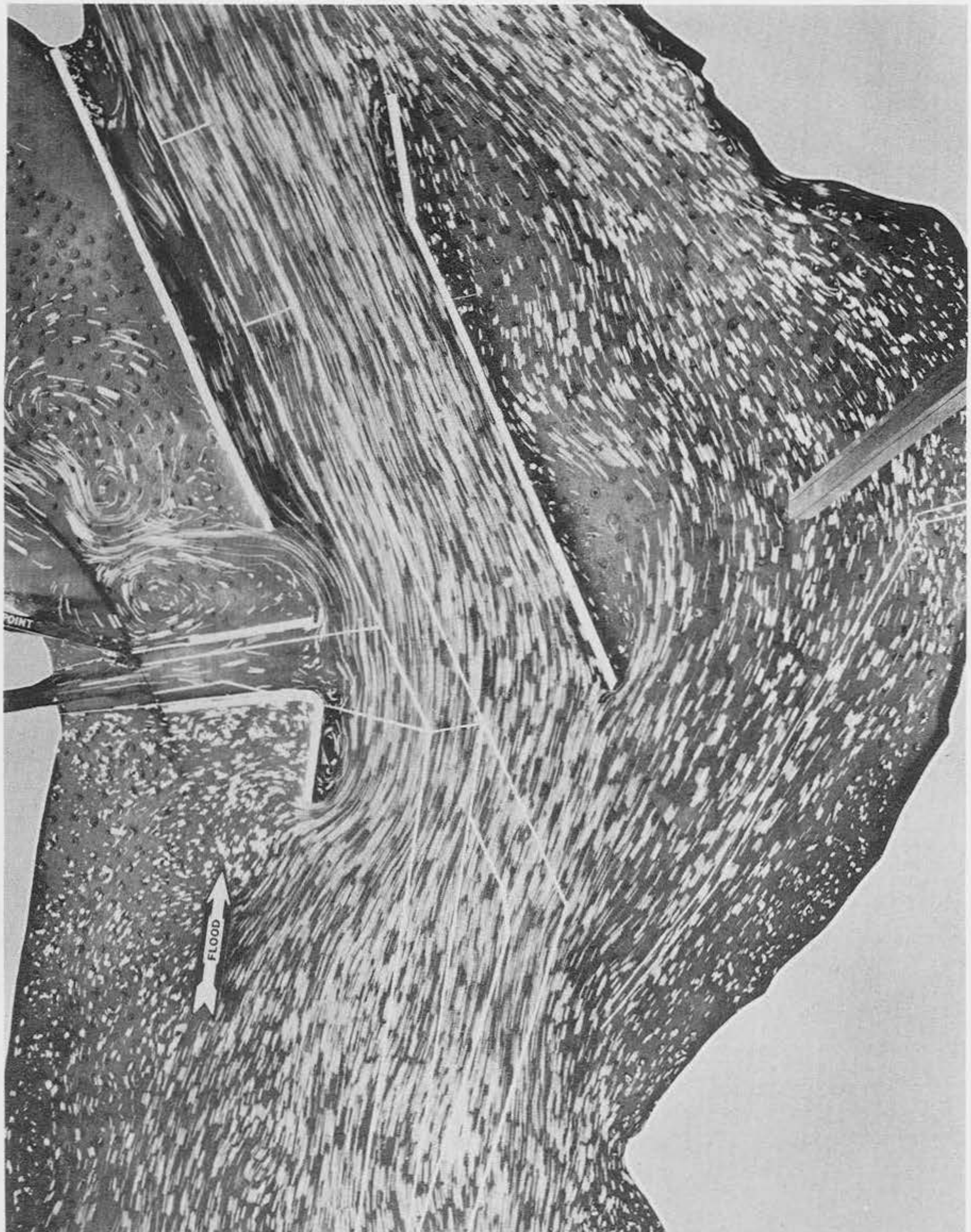


Plan 11C, Strength of Flood

Photograph 30

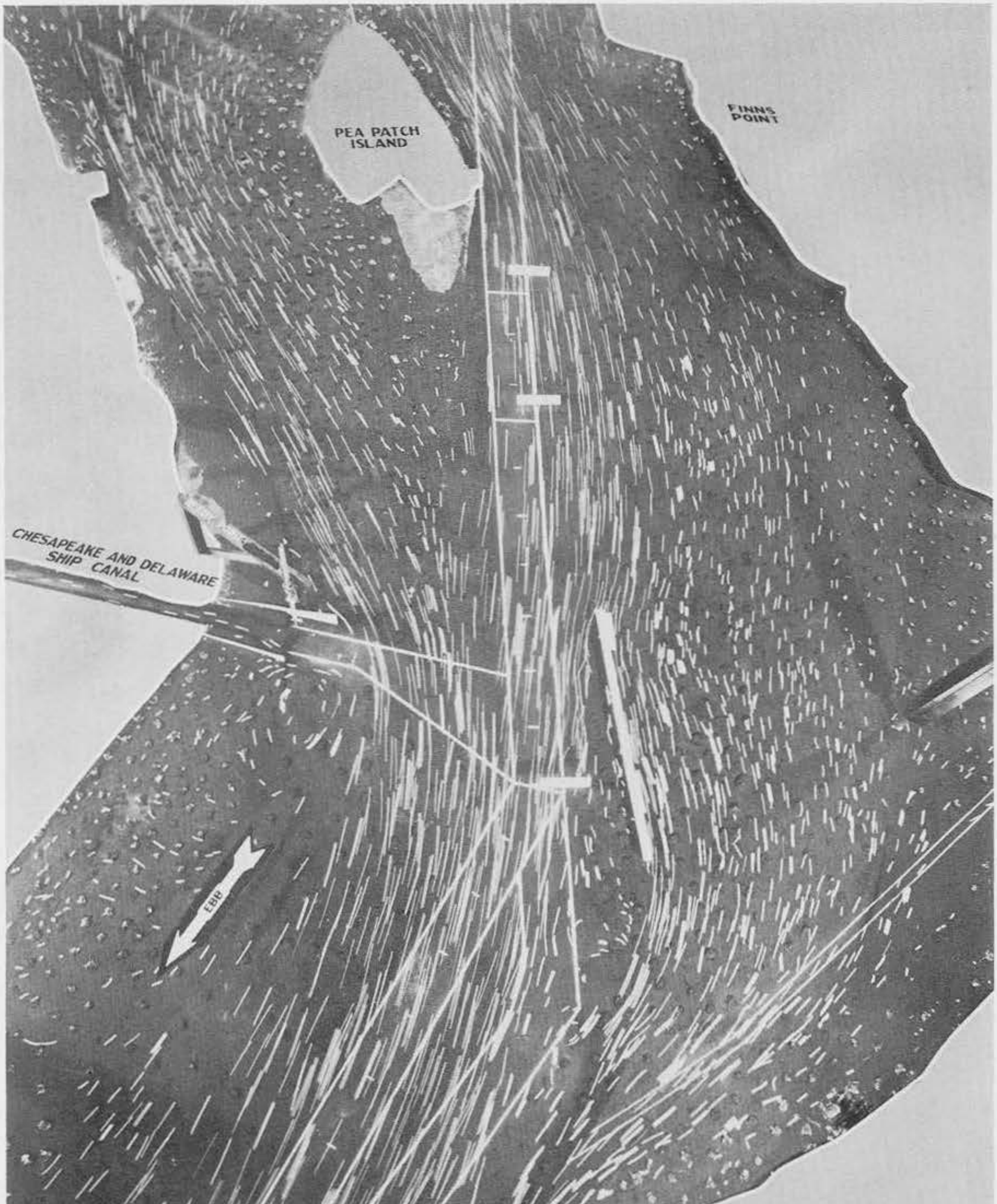


Plan 12, Strength of Ebb

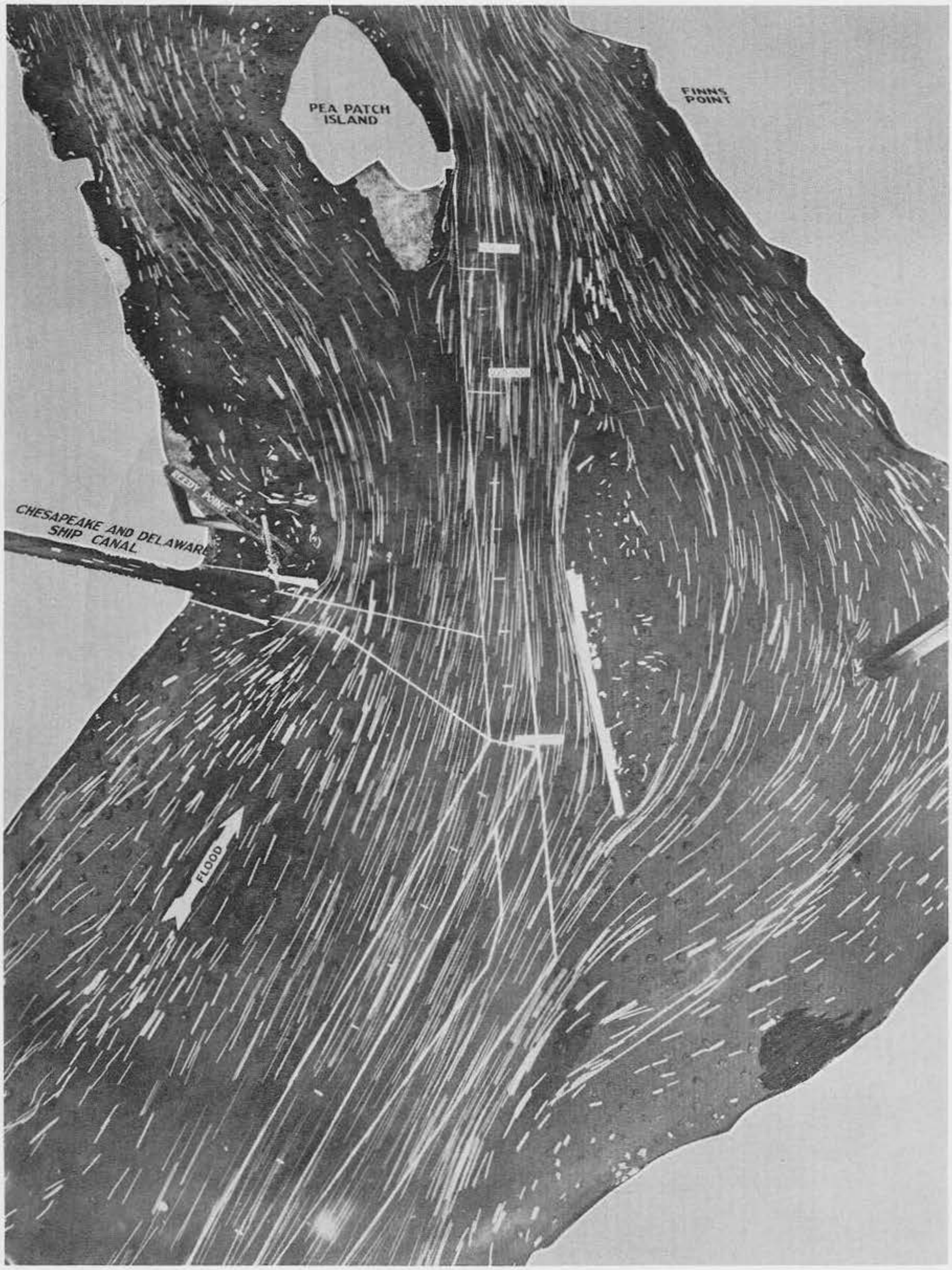


Plan 12, Strength of Flood

Photograph 32

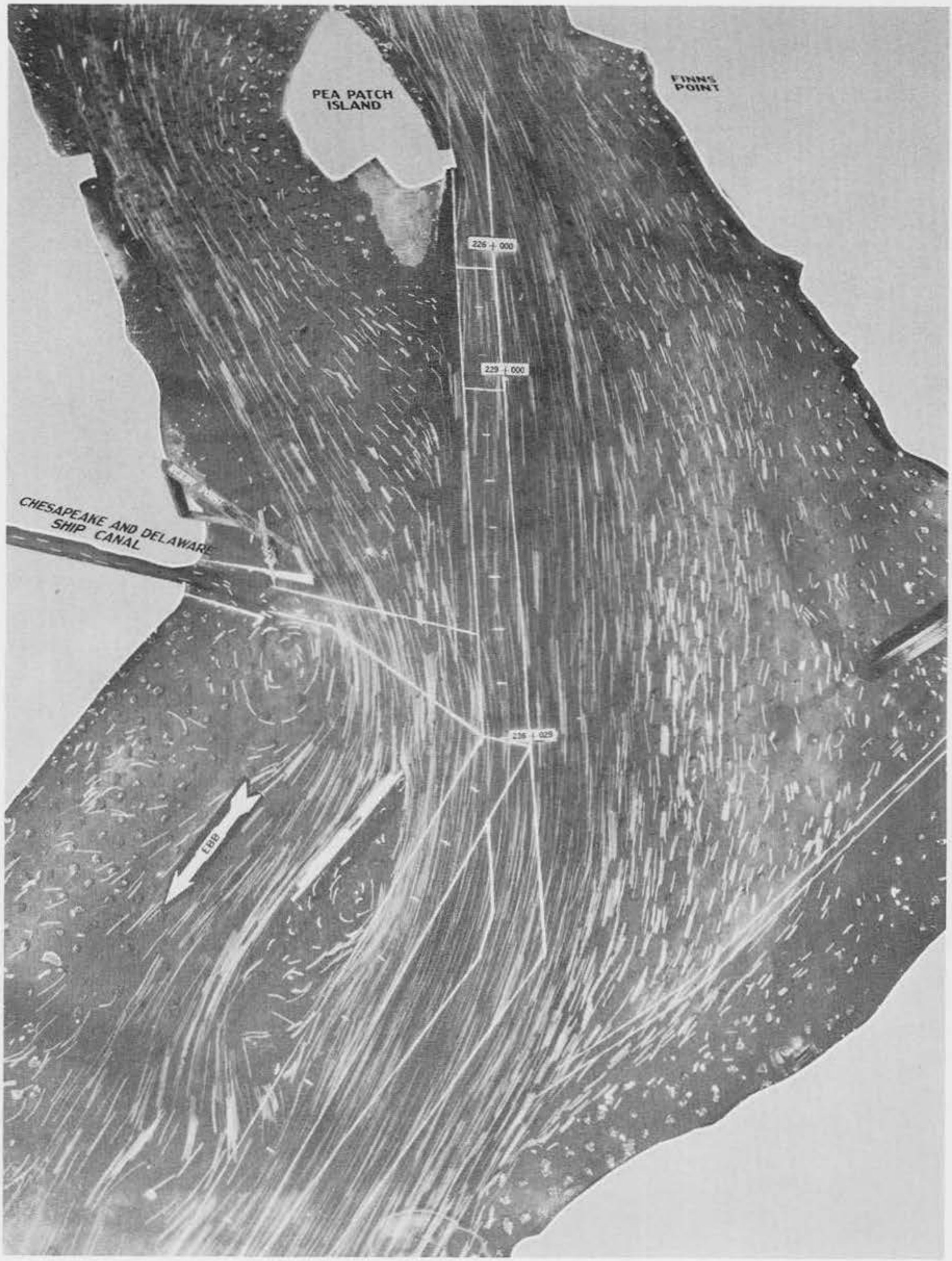


Plan 13, Strength of Ebb

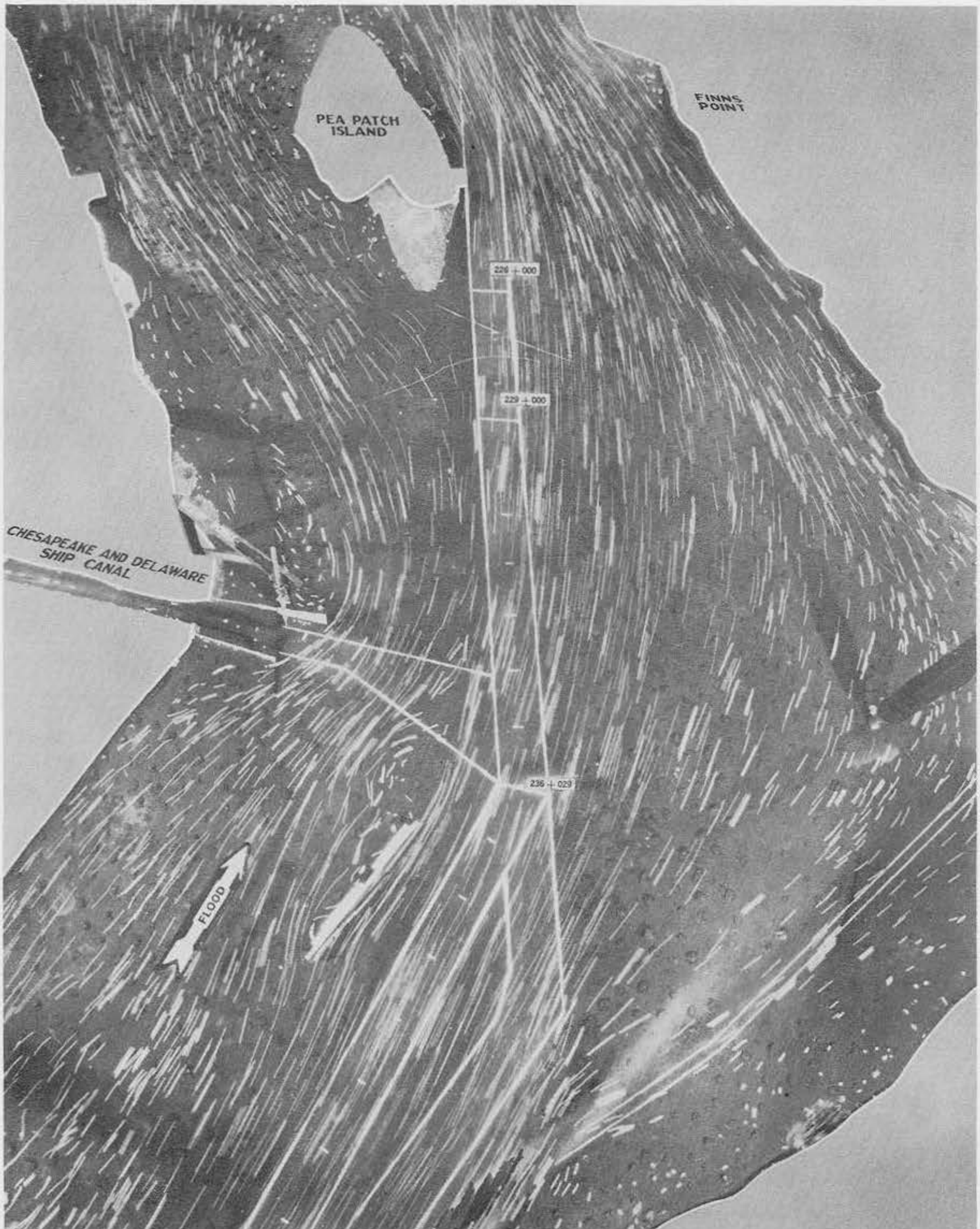


Plan 13, Strength of Flood

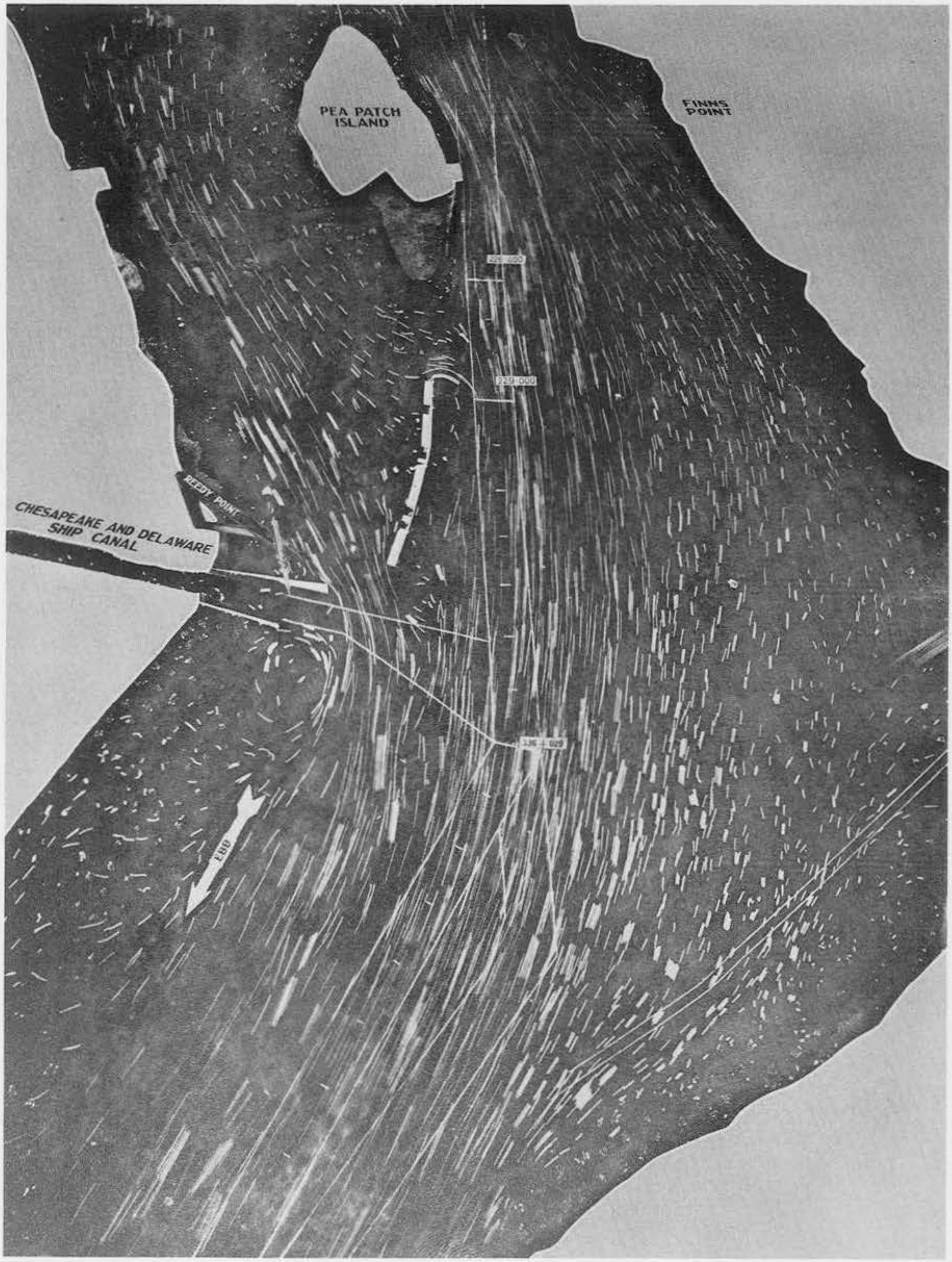
Photograph 34



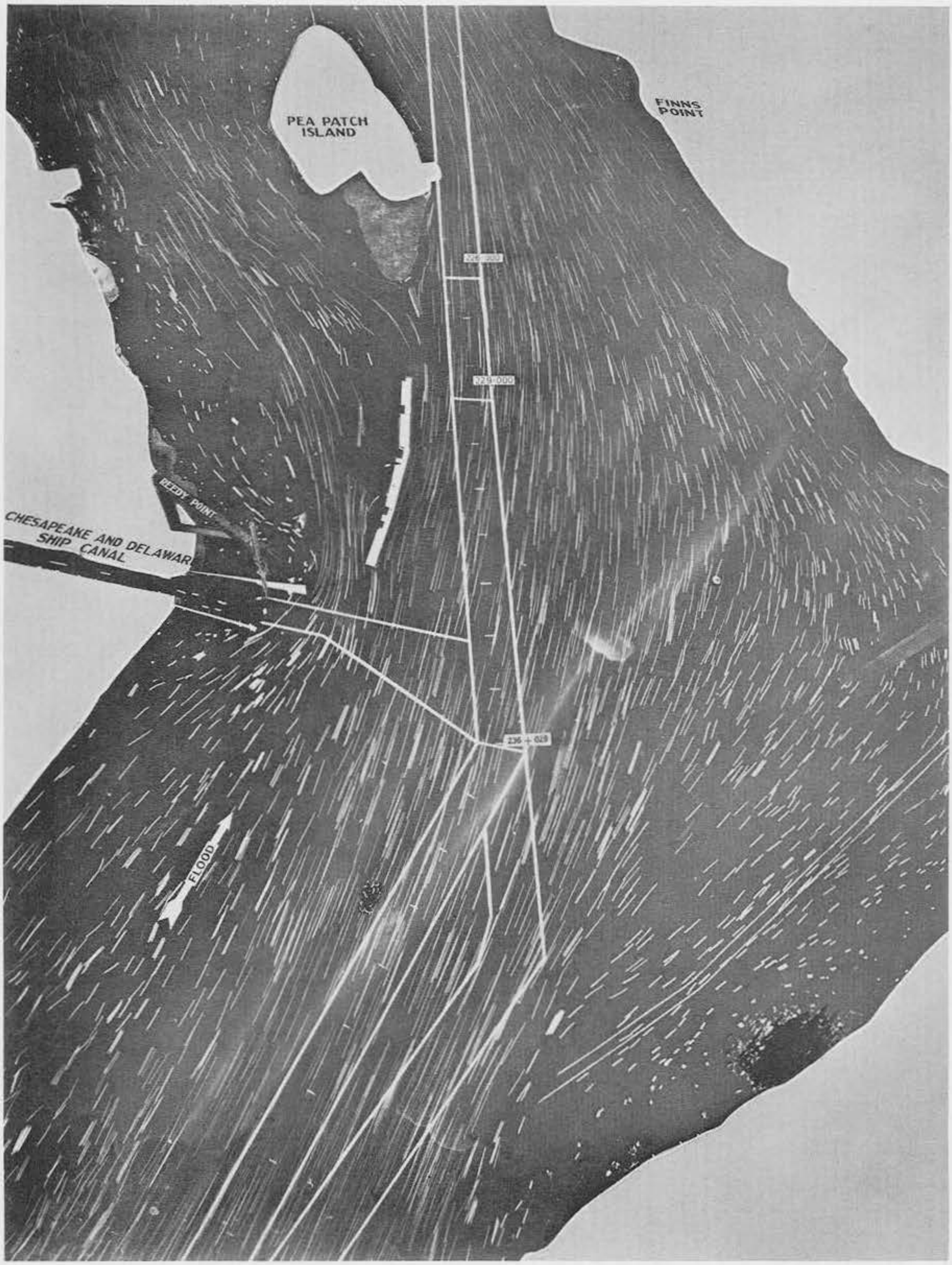
Plan 14, Strength of Ebb



Plan 14, Strength of Flood



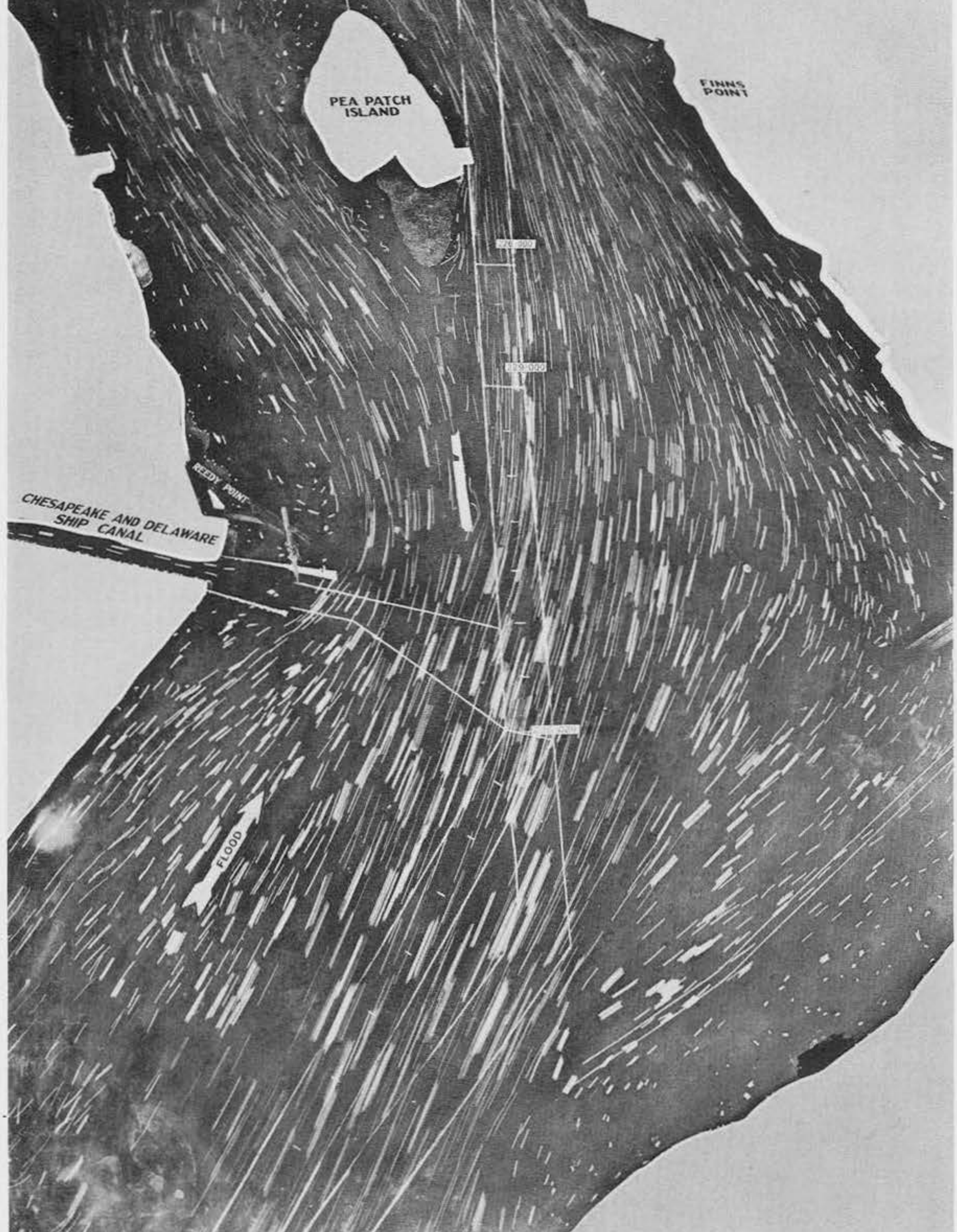
Plan 15, Strength of Ebb



Plan 15, Strength of Flood

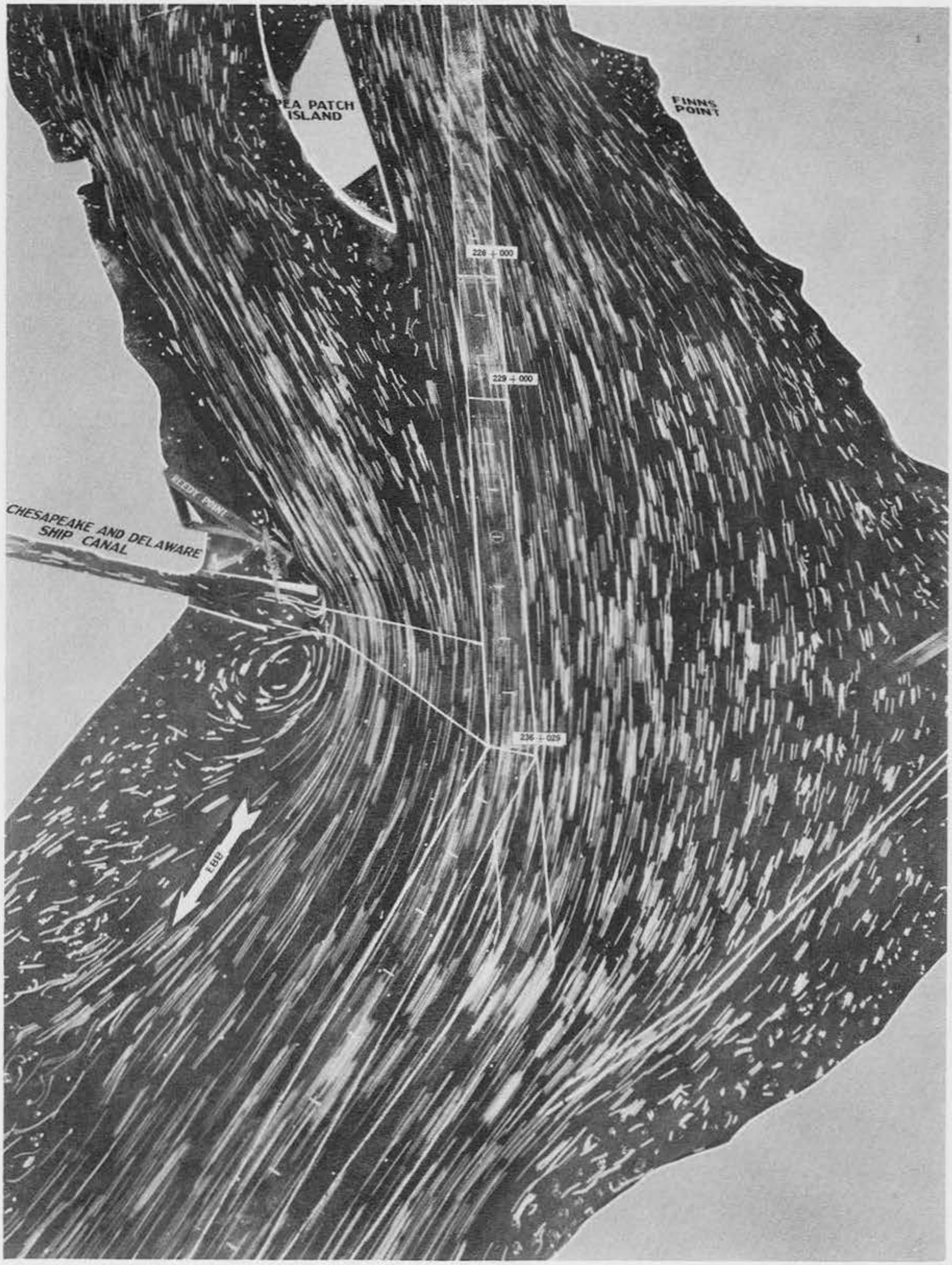
Photograph 38

Plan 16, Strength of Ebb

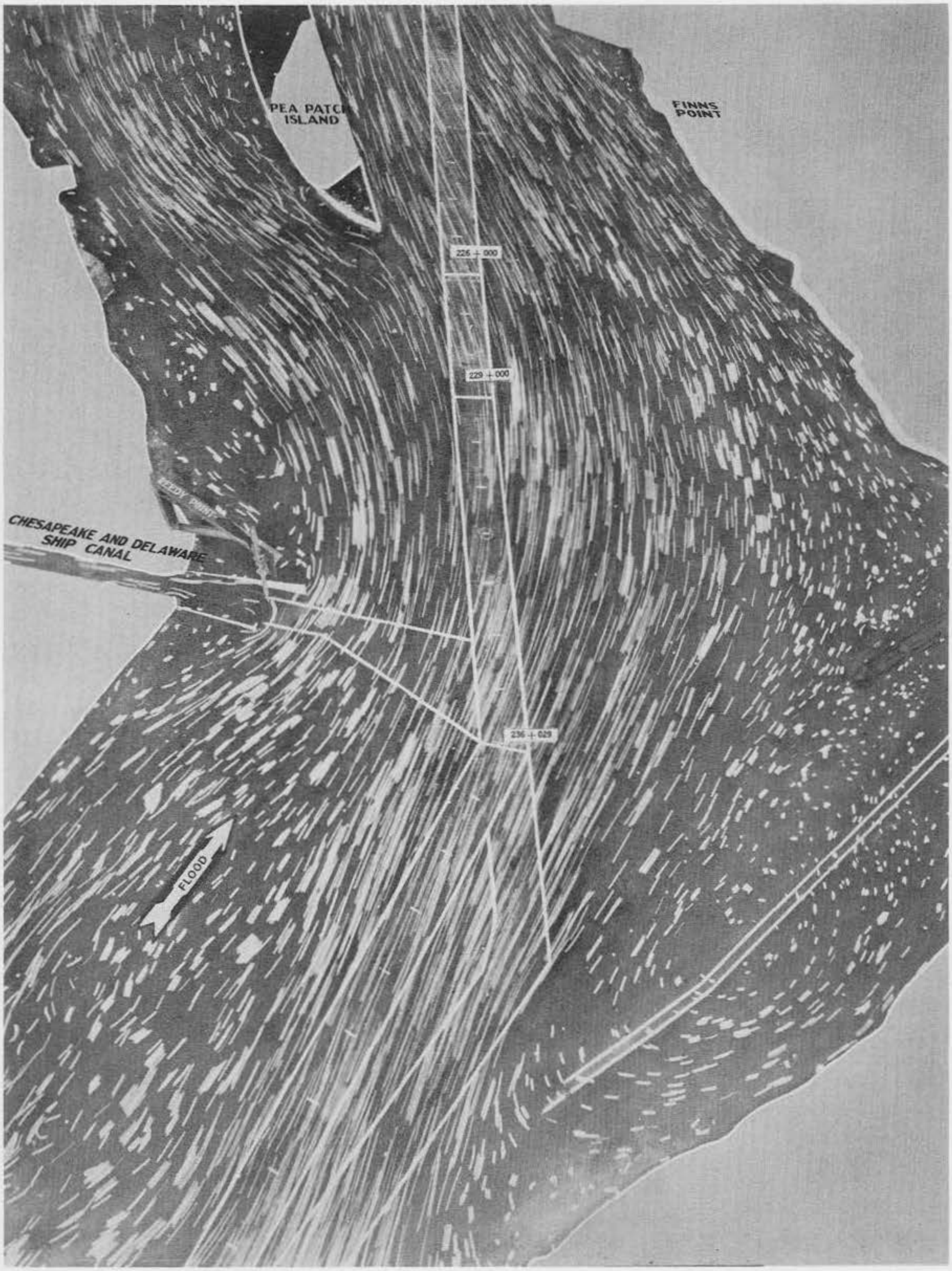


Plan 16, Strength of Flood

Photograph 40

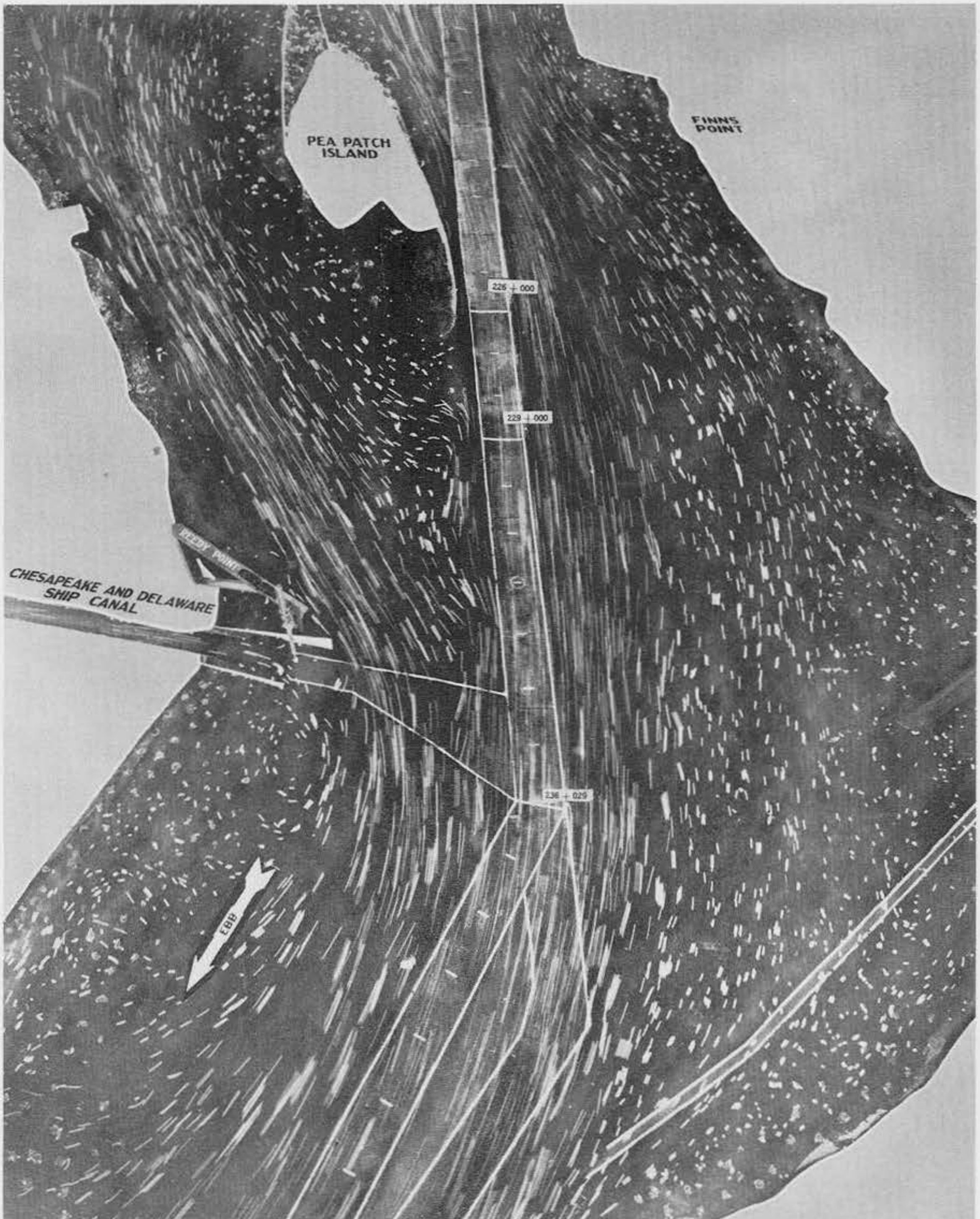


Plan 17, Strength of Ebb



Plan 17, Strength of Flood

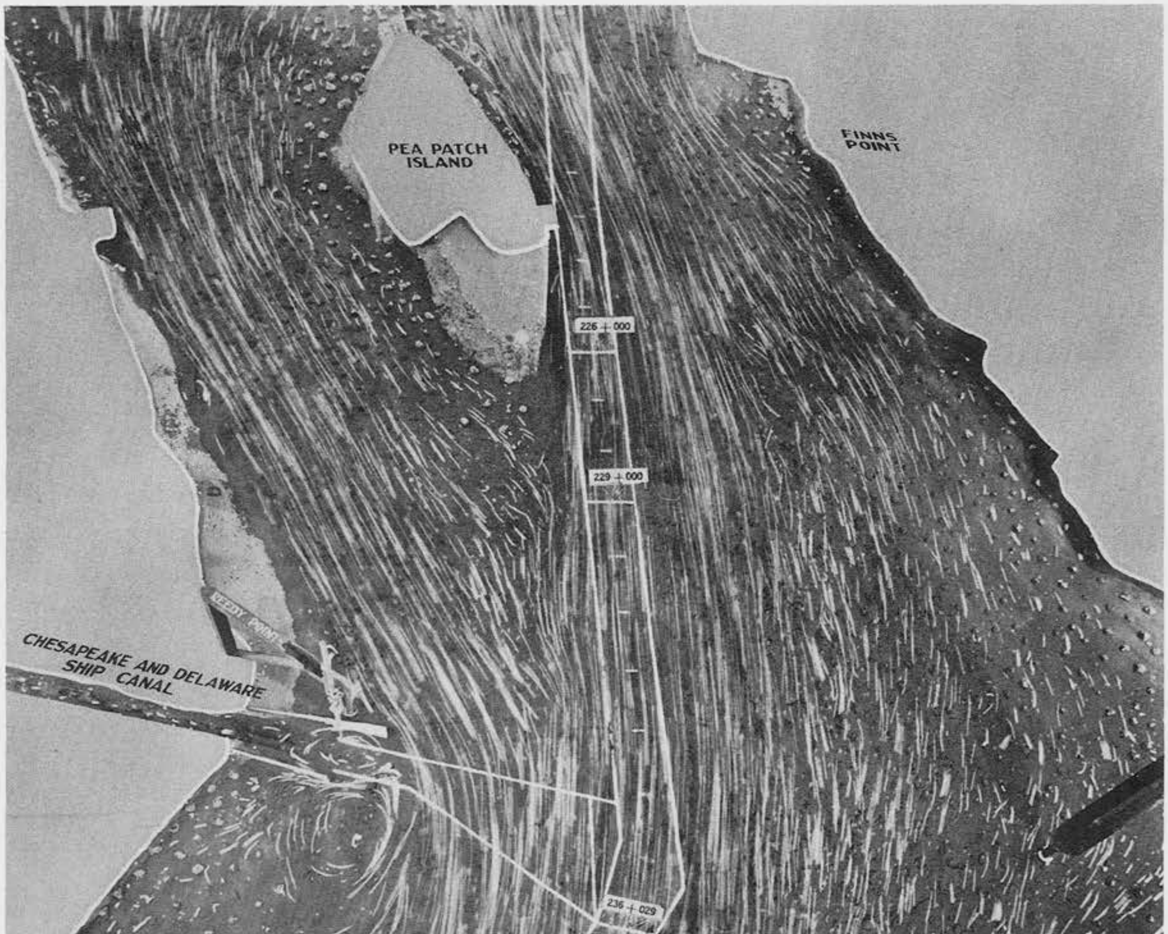
Photograph 42



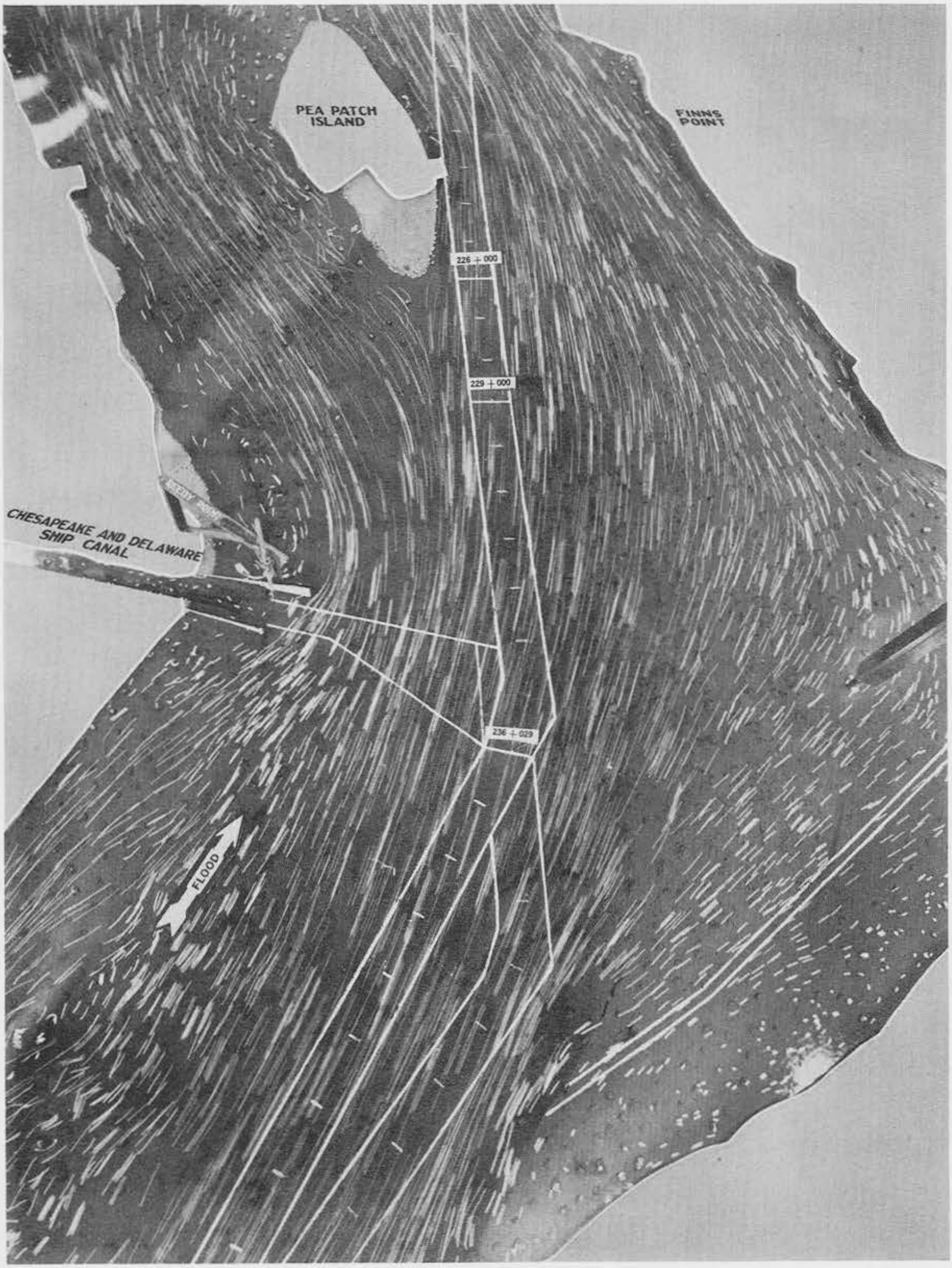
Plan 18, Strength of Ebb

Plan 18, Strength of Flood

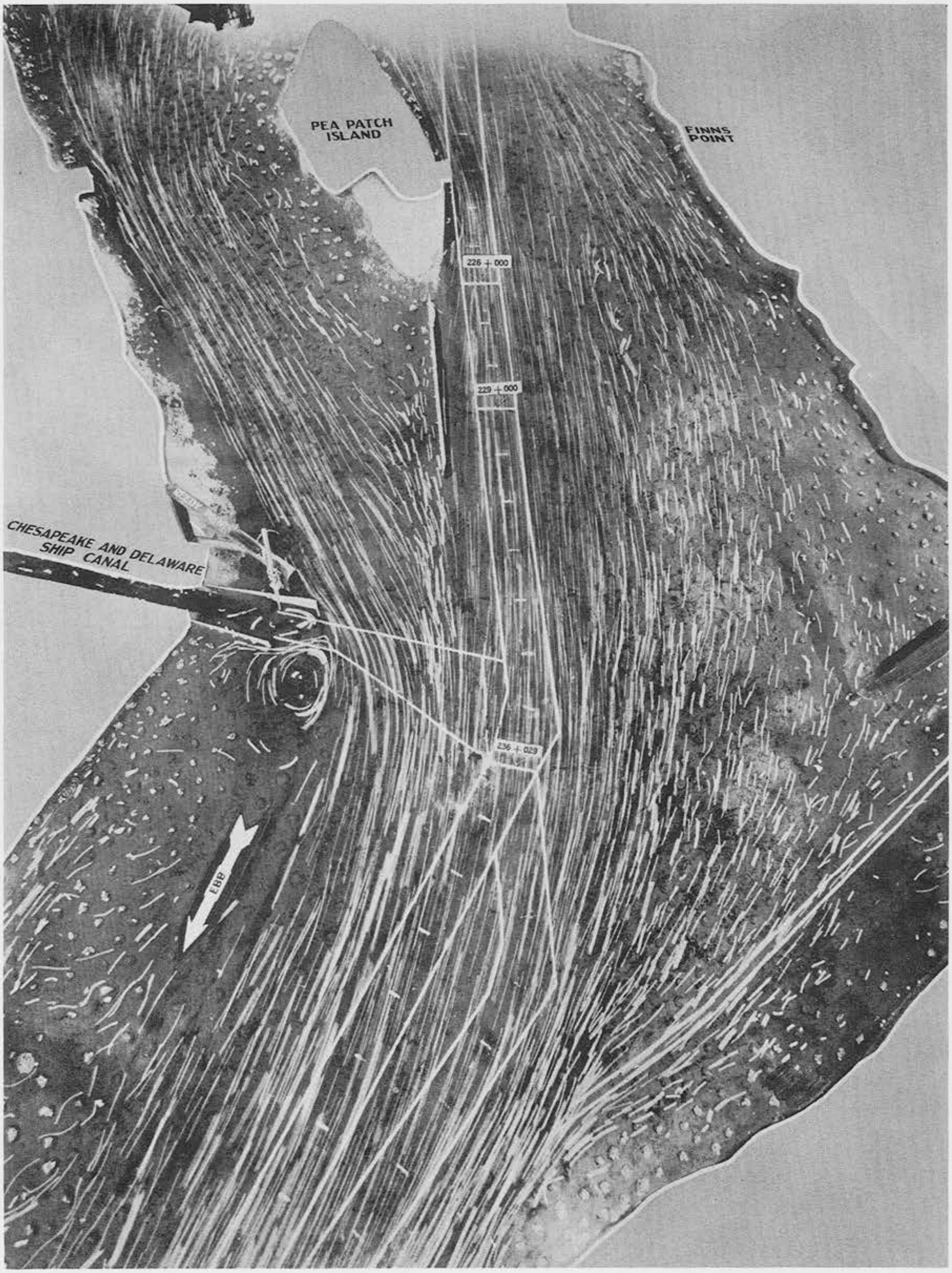
Photograph 44



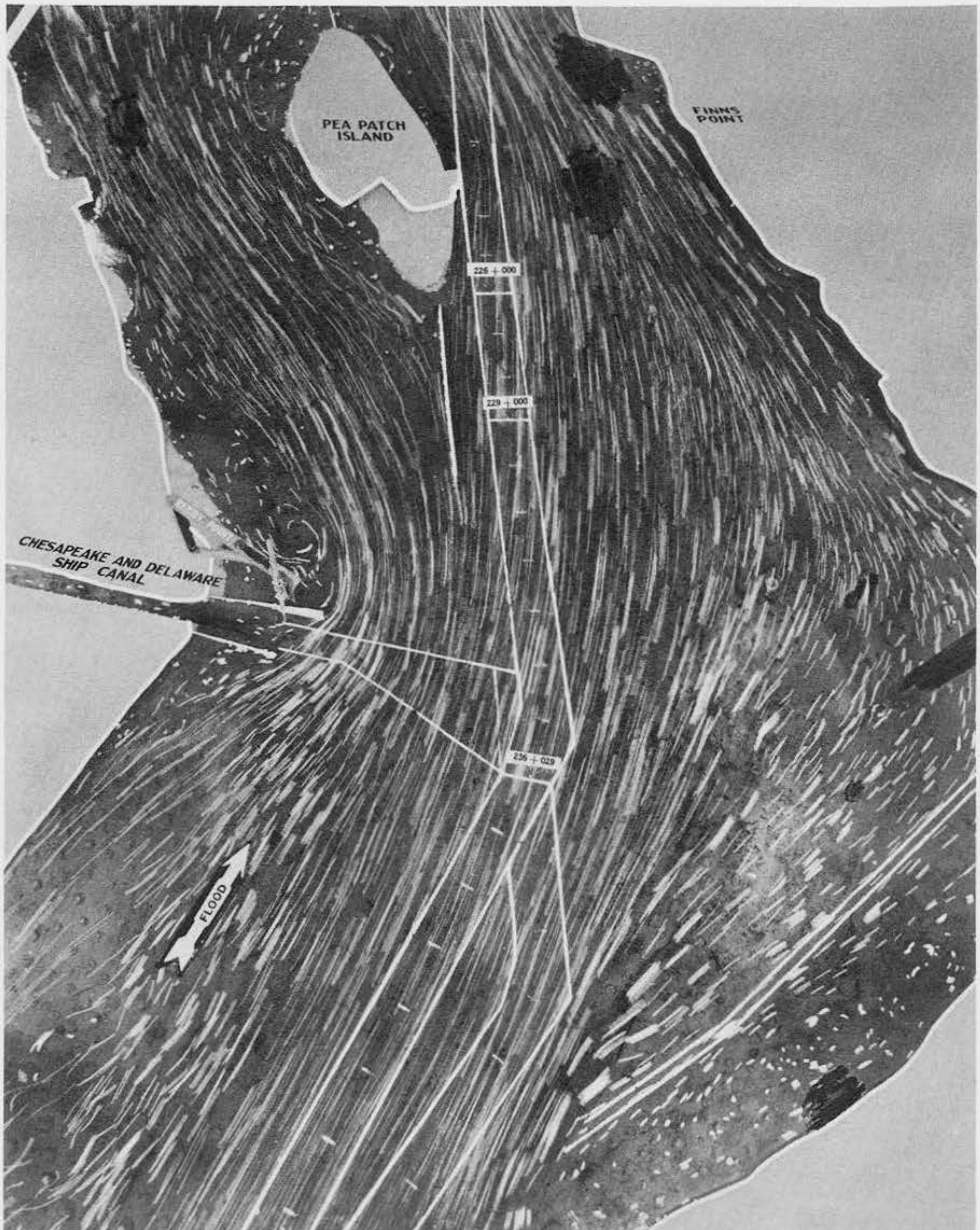
Plan 19, Strength of Ebb



Plan 19, Strength of Flood

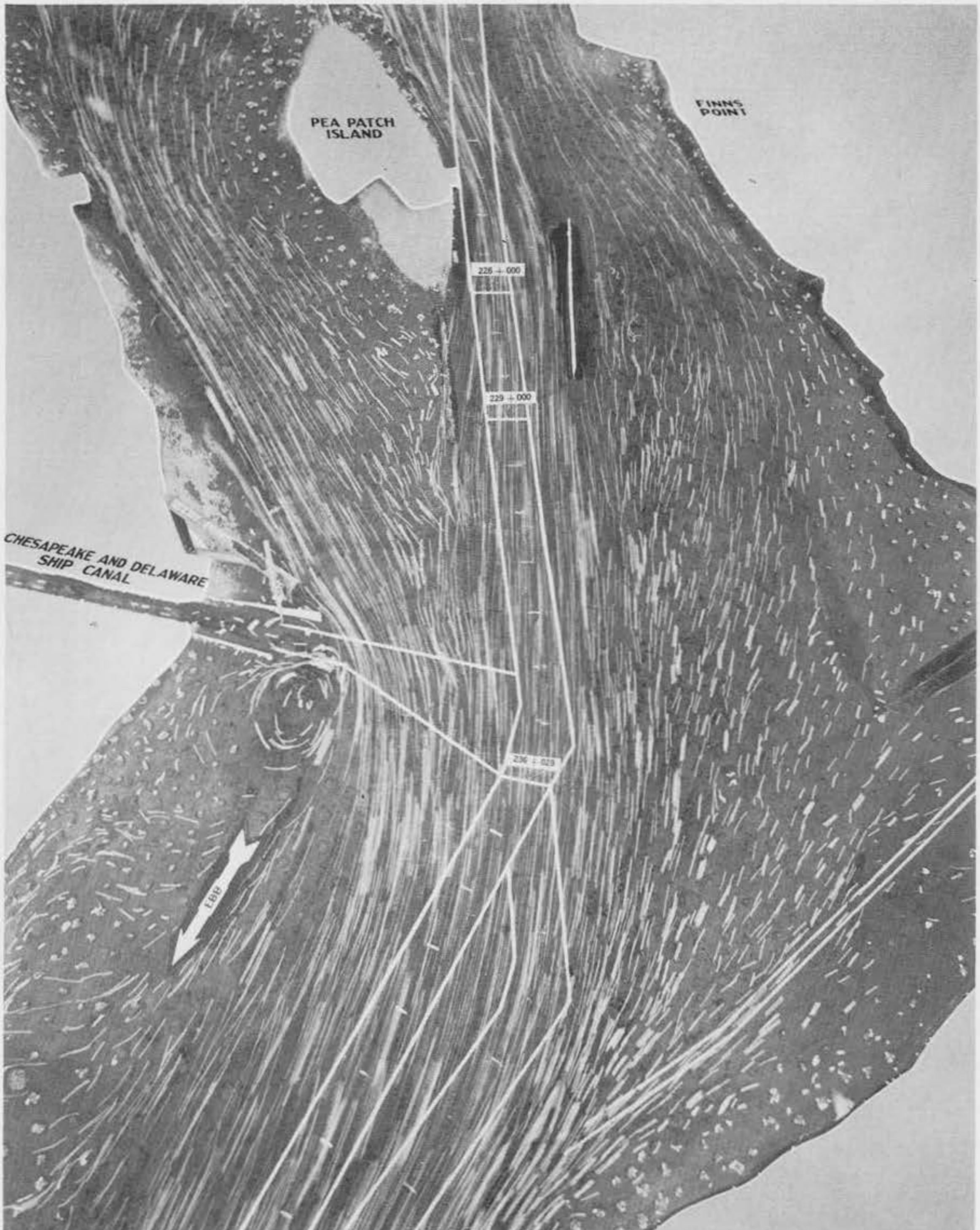


Plan 20, Strength of Ebb

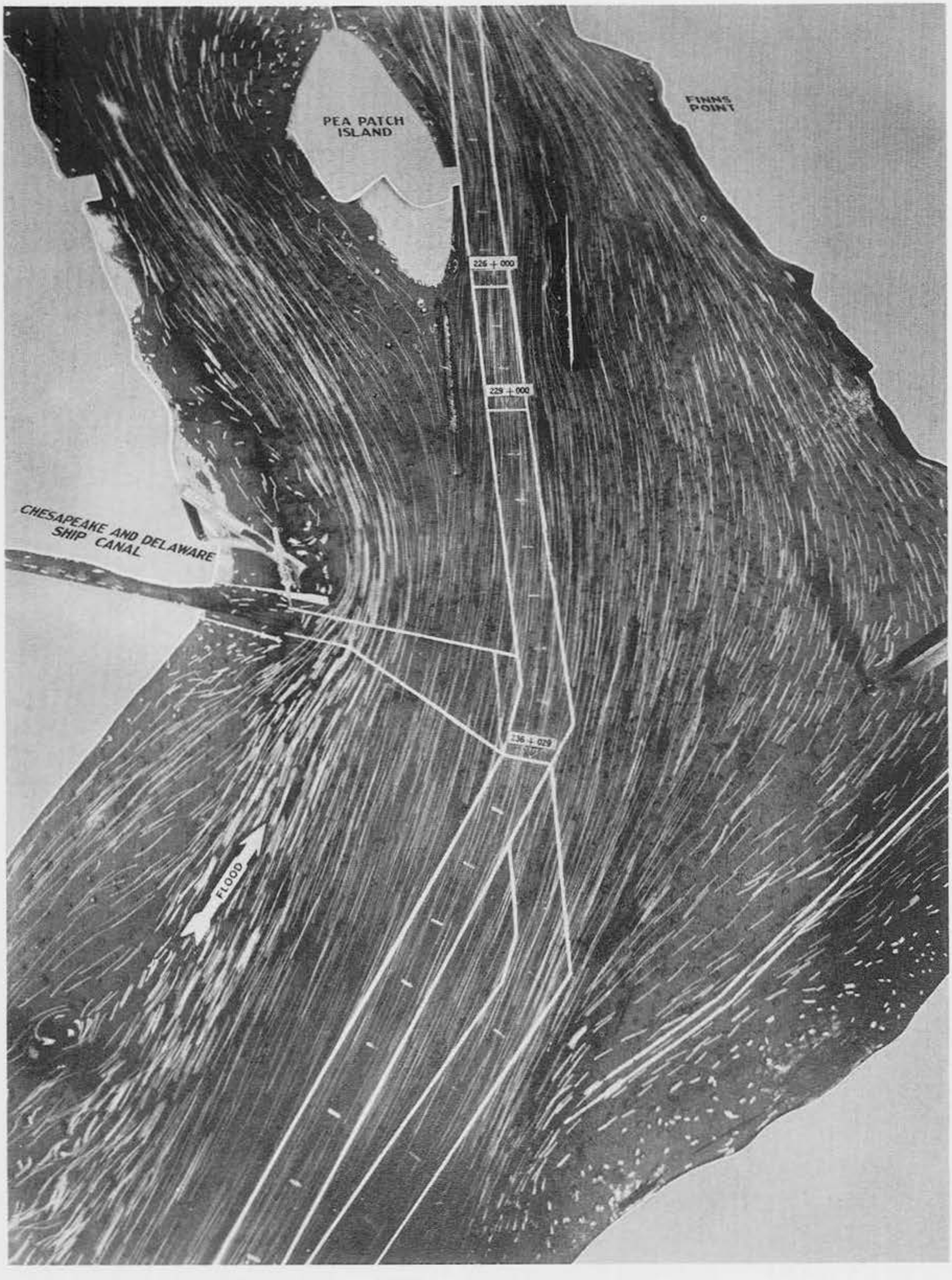


Plan 20, Strength of Flood

Photograph 48

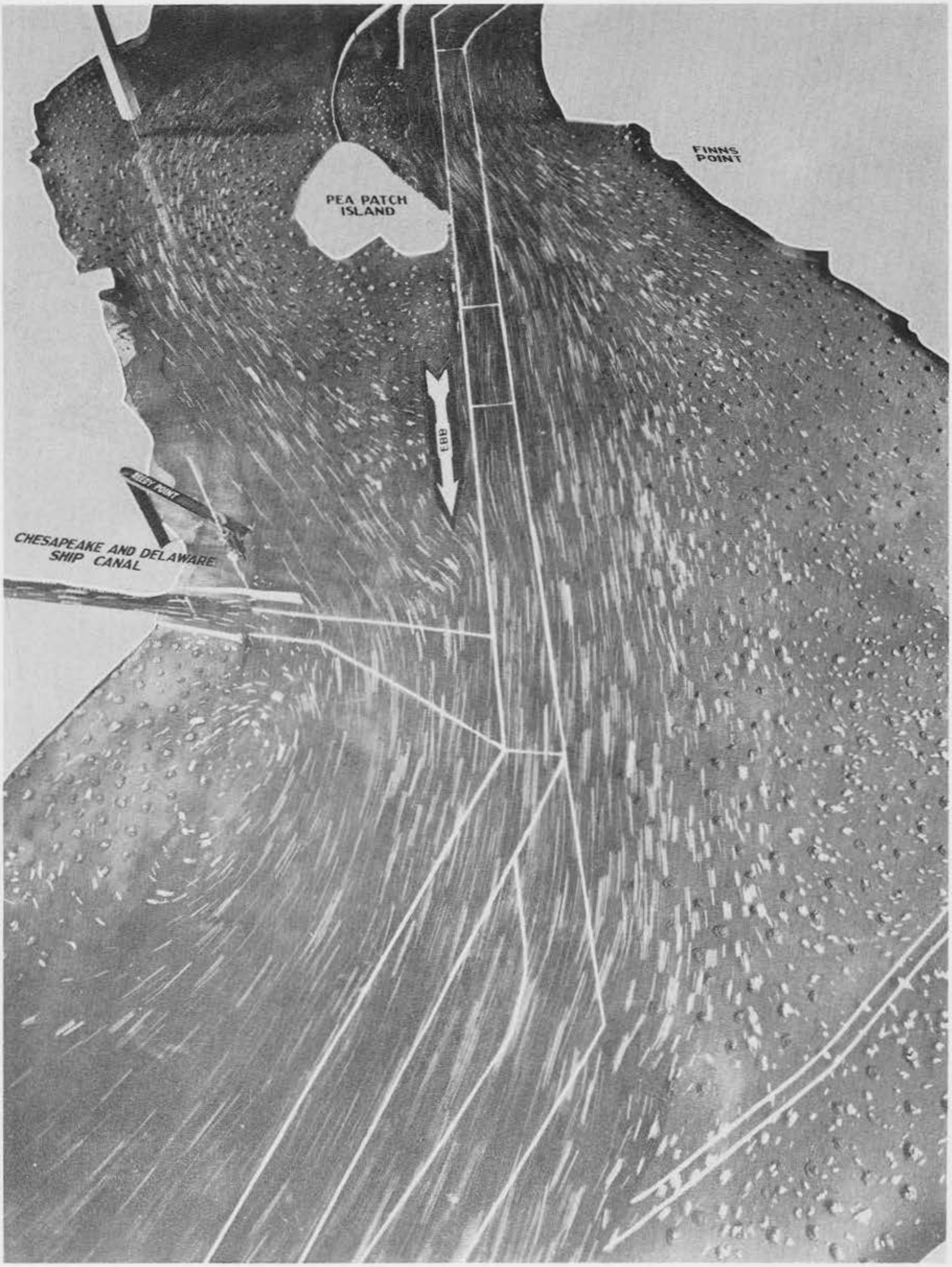


Plan 21, Strength of Ebb

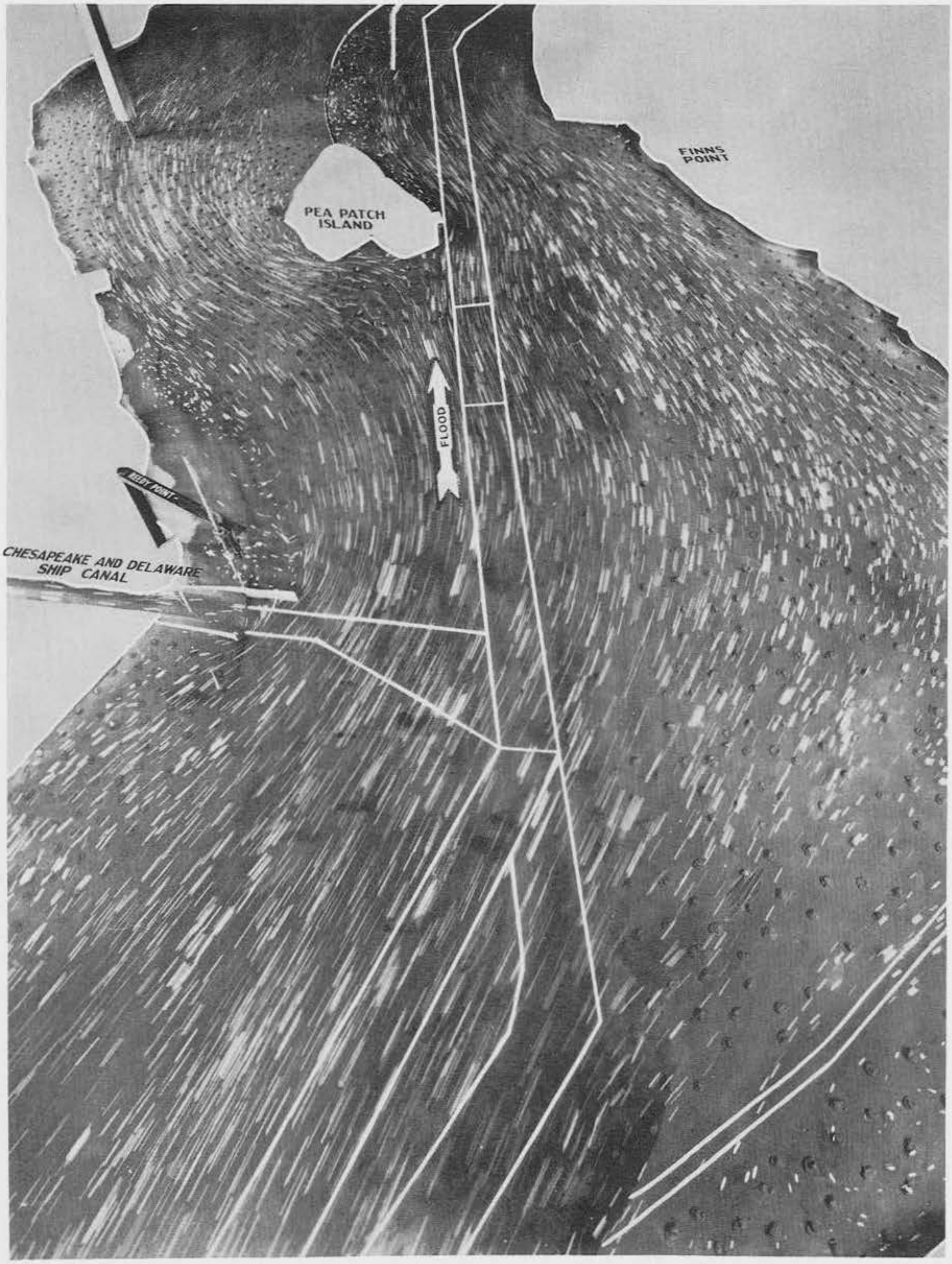


Plan 21, Strength of Flood

Photograph 50



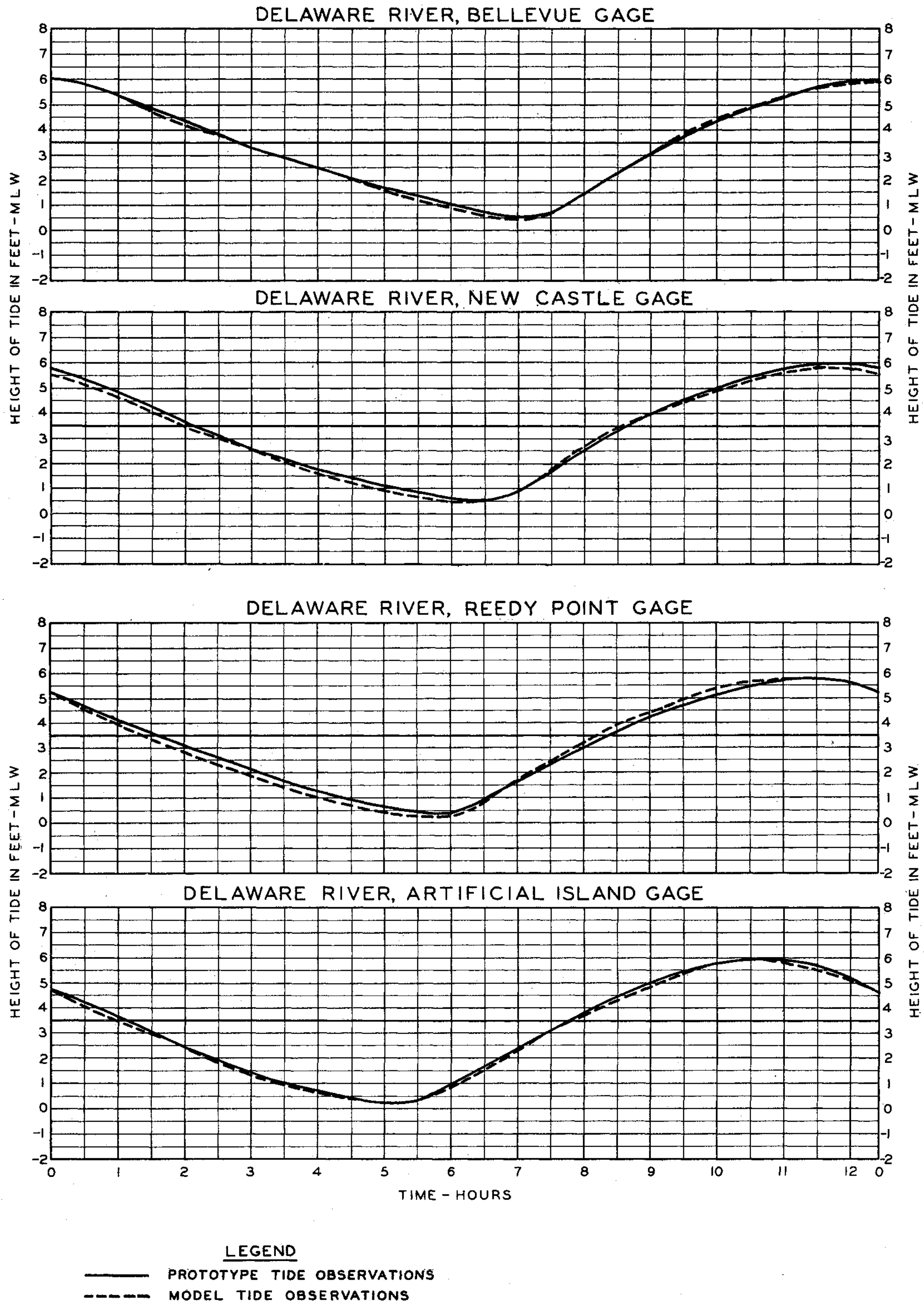
Plan 22, Strength of Ebb



Plan 22, Strength of Flood

Photograph 52

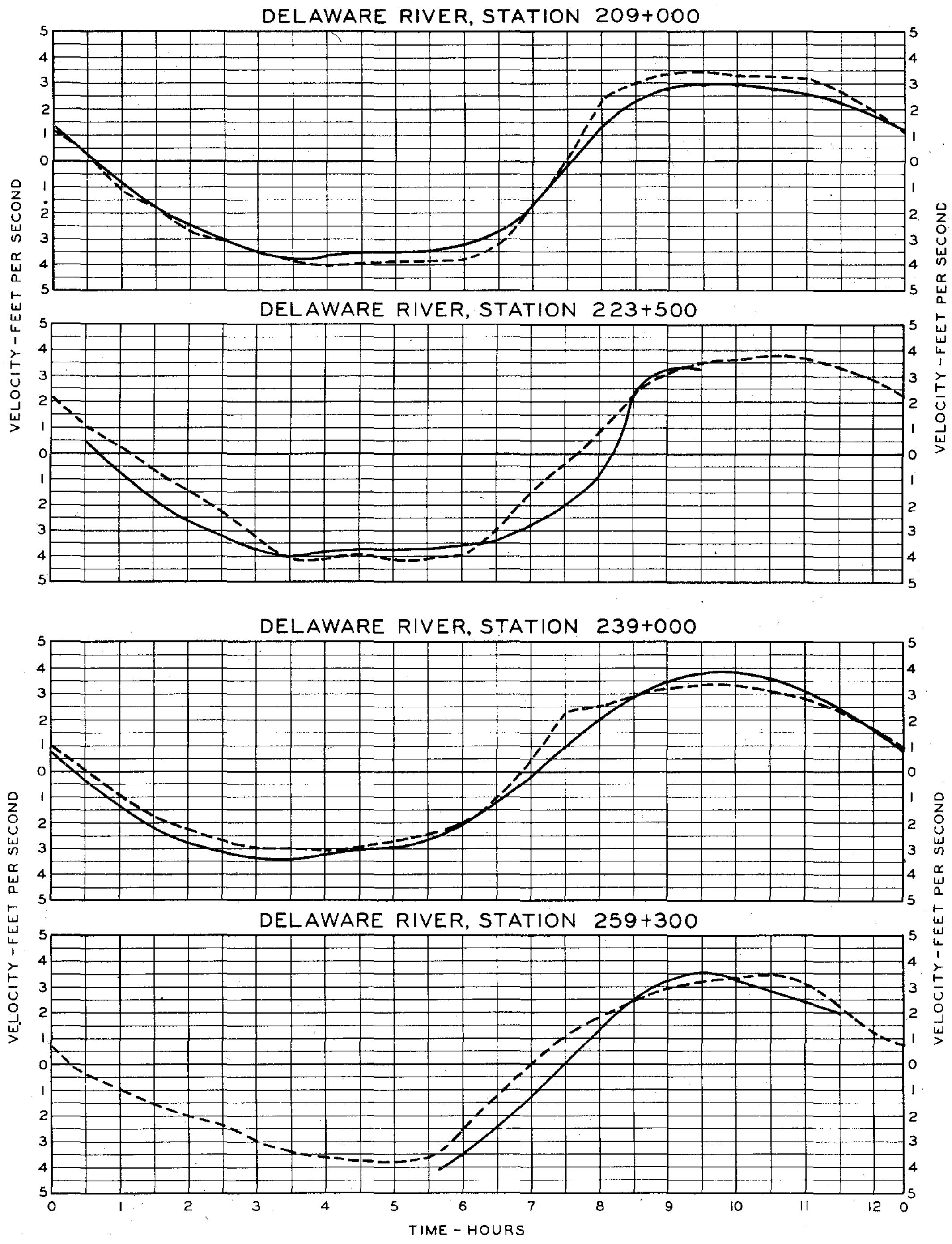
PLATES



NOTE: TIME IS EXPRESSED IN HOURS AFTER THE MOON'S TRANSIT OVER GREENWICH, LESS FIVE HOURS.

TIDE OBSERVATIONS

VERIFICATION TEST



LEGEND

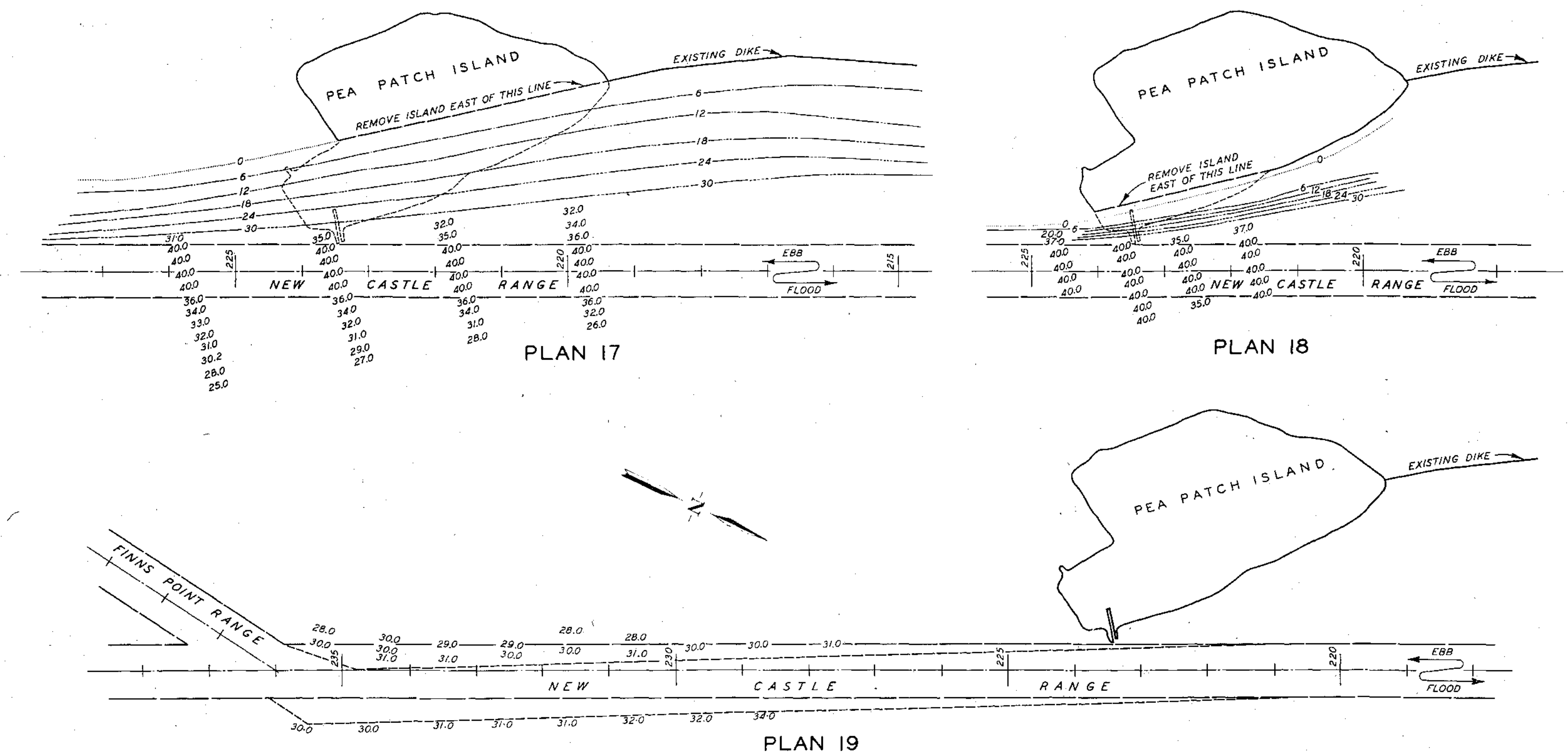
—— PROTOTYPE VELOCITY OBSERVATIONS

- - - - MODEL VELOCITY OBSERVATIONS

NOTE: TIME IS EXPRESSED IN HOURS AFTER THE MOON'S TRANSIT OVER GREENWICH, LESS FIVE HOURS.

VELOCITY OBSERVATIONS

VERIFICATION TEST



LEGEND

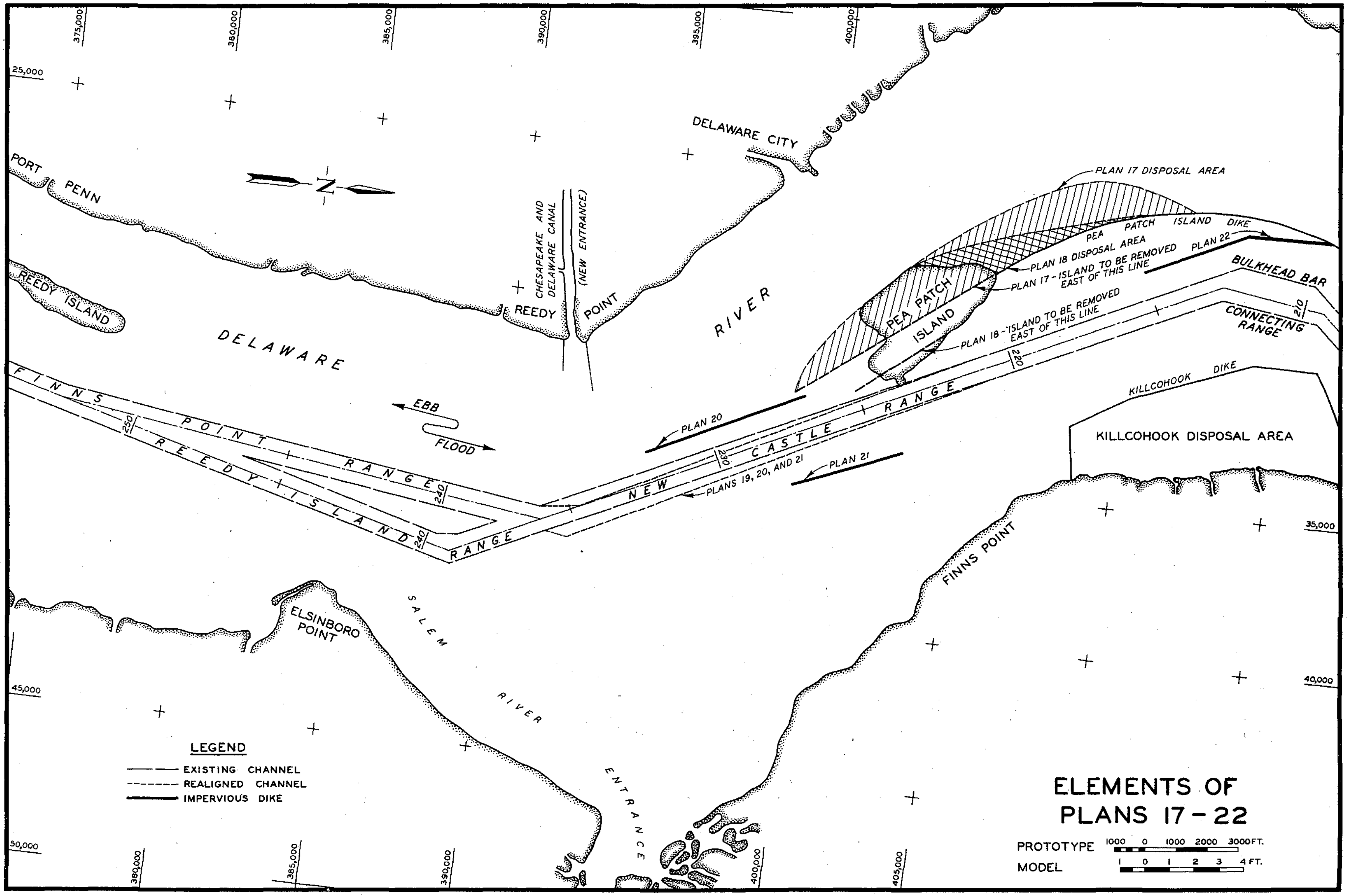
———— EXISTING CHANNEL
- - - - - - REALIGNED CHANNEL

NOTE: SOUNDINGS REFER TO U. S. ENGINEER DATUM, WHICH IS 2.90 FT. BELOW MEAN SEA LEVEL, SANDY HOOK, N. J.

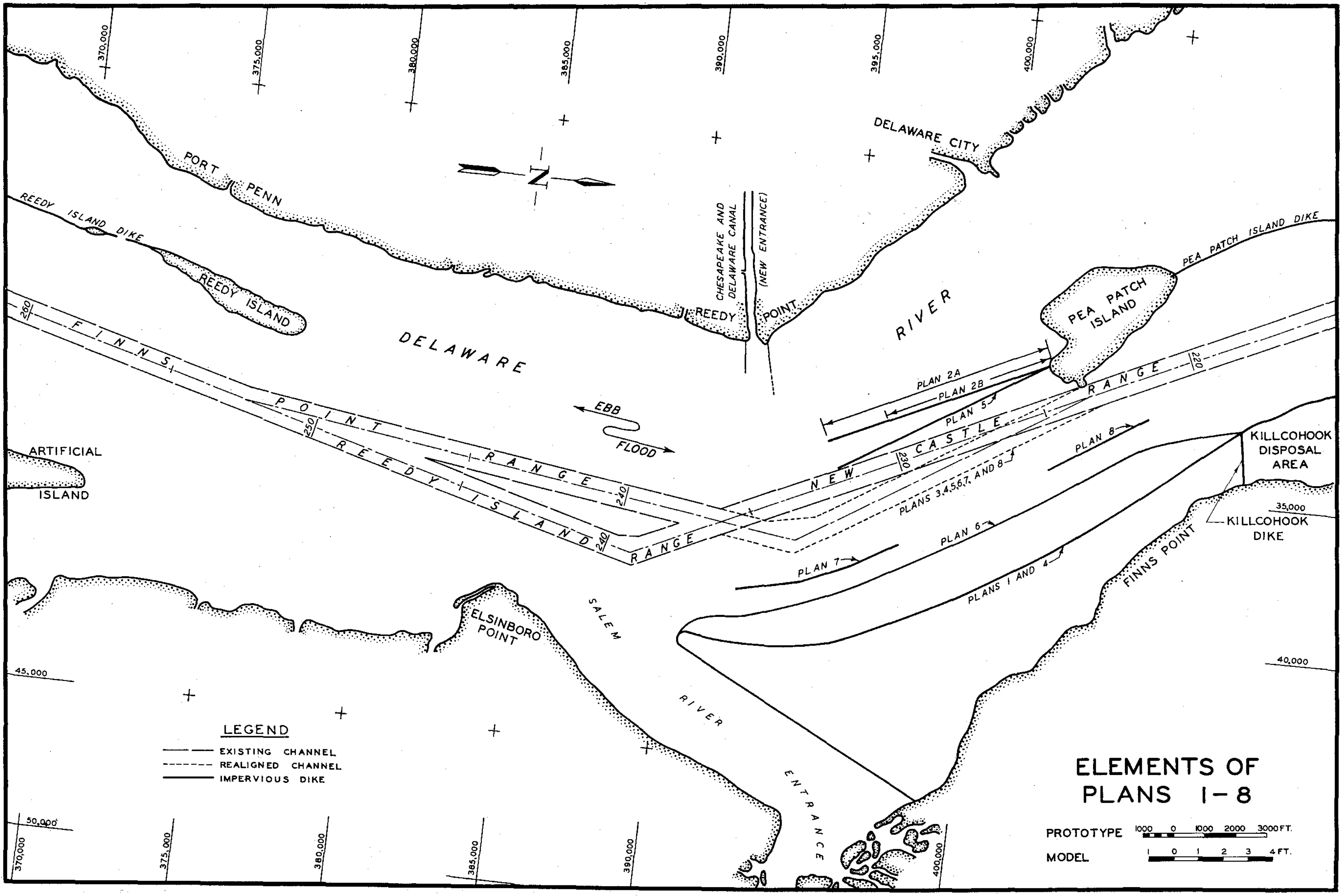
ANTICIPATED HYDROGRAPHY PLANS 17-19

PROTOTYPE 500 0 500 1000 1500 2000 FT.
MODEL 1 0 1 2 FT.

PLATE 4



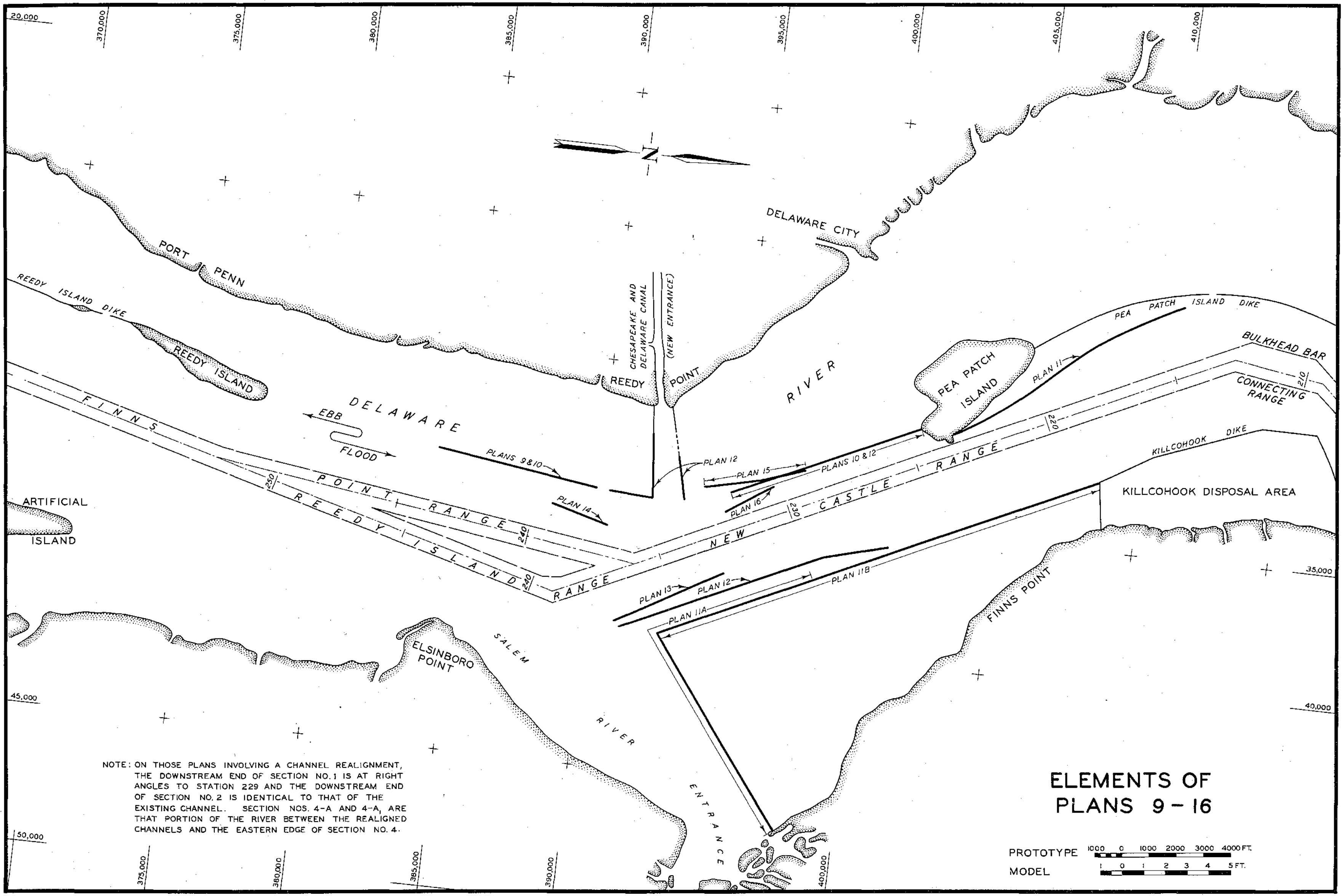
ELEMENTS OF PLANS 17 - 22

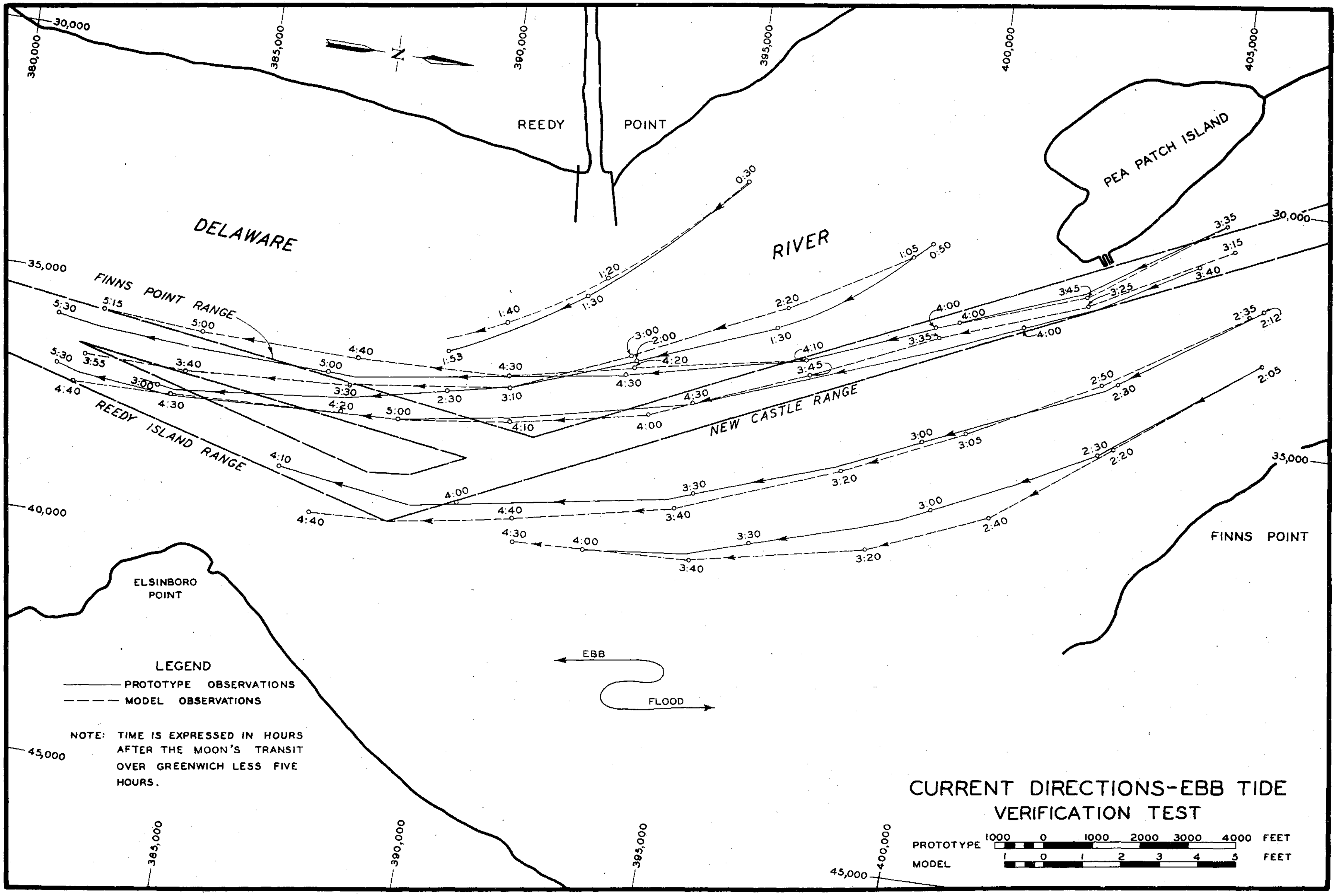


ELEMENTS OF PLANS 1 - 8

PLATE 5

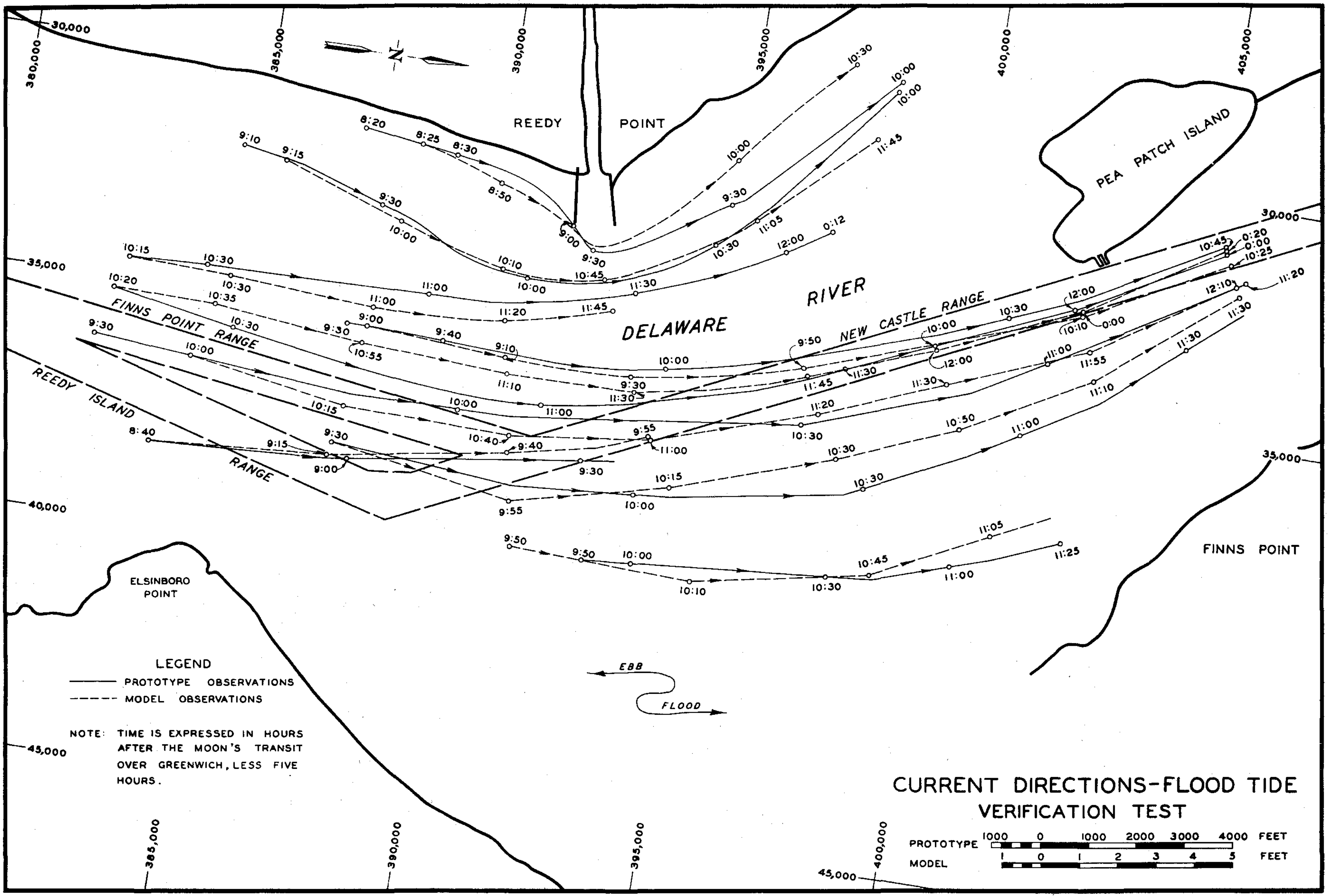
PLATE 6


ELEMENTS OF
PLANS 9 - 16
NOTE: ON THOSE PLANS INVOLVING A CHANNEL REALIGNMENT, THE DOWNSTREAM END OF SECTION NO. 1 IS AT RIGHT ANGLES TO STATION 229 AND THE DOWNSTREAM END OF SECTION NO. 2 IS IDENTICAL TO THAT OF THE EXISTING CHANNEL. SECTION NOS. 4-A AND 4-A, ARE THAT PORTION OF THE RIVER BETWEEN THE REALIGNED CHANNELS AND THE EASTERN EDGE OF SECTION NO. 4.
PROTOTYPE 1000 0 1000 2000 3000 4000 FT.
MODEL 1 0 1 2 3 4 5 FT.
DELAWARE CITY
PORT PENN
REEDY ISLAND DIKE
REEDY ISLAND
CHESAPEAKE AND DELAWARE CANAL
(NEW ENTRANCE)
REEDY
POINT
DELAWARE
RIVER
EBB
FLOOD
PEA PATCH ISLAND
PEA PATCH ISLAND DIKE
BULKHEAD BAR
CONNECTING RANGE
KILLCOHOOK DIKE
KILLCOHOOK DISPOSAL AREA
FINNS POINT RANGE
REEDY ISLAND RANGE
NEW CASTLE RANGE
ARTIFICIAL ISLAND
ELSINBORO POINT
SALEM RIVER ENTRANCE
FINNS POINT
PLANS 9&10
PLAN 12
PLAN 15
PLANS 10 & 12
PLAN 11
PLAN 16
PLAN 14
PLAN 13
PLAN 11A
PLAN 11B
230
240
250
220
210
20,000
35,000
40,000
45,000
50,000
370,000
375,000
380,000
385,000
390,000
395,000
400,000
405,000
410,000
N

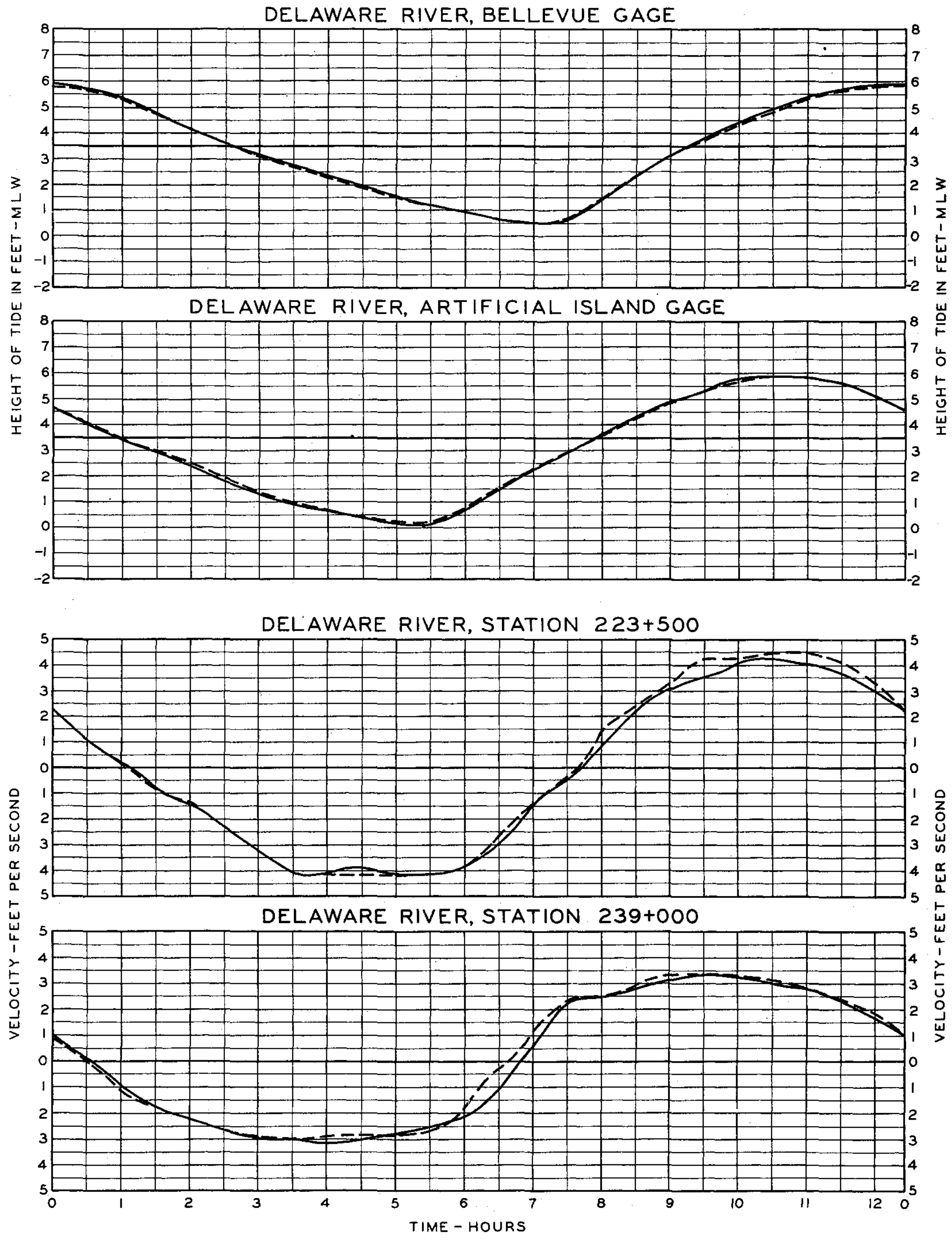


CURRENT DIRECTIONS-EBB TIDE
VERIFICATION TEST

PLATE 7



CURRENT DIRECTIONS-FLOOD TIDE
VERIFICATION TEST



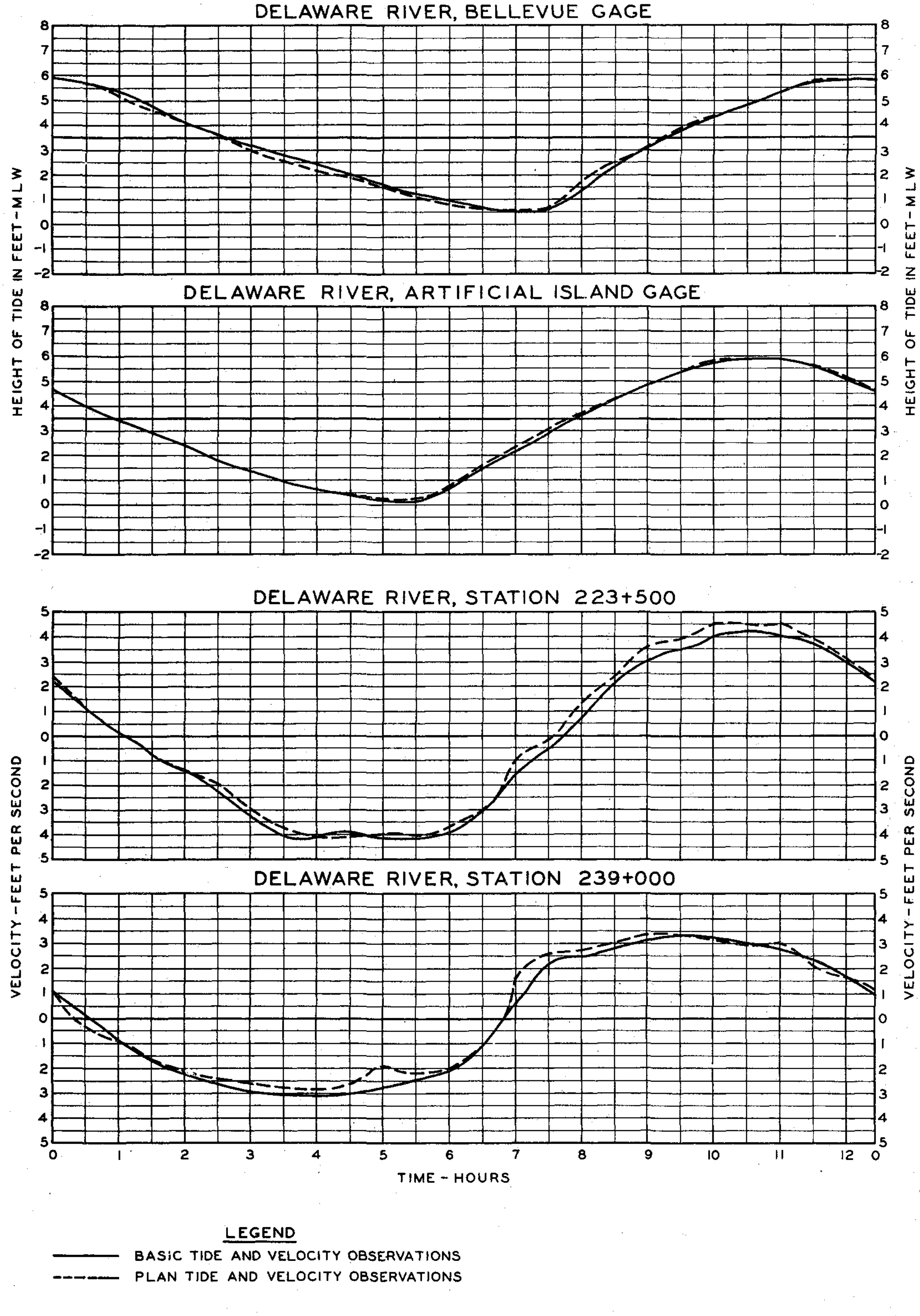
LEGEND

——— BASIC TIDE AND VELOCITY OBSERVATIONS

– – – – PLAN TIDE AND VELOCITY OBSERVATIONS

NOTE: TIME IS EXPRESSED IN HOURS AFTER THE MOON'S TRANSIT OVER GREENWICH, LESS FIVE HOURS.

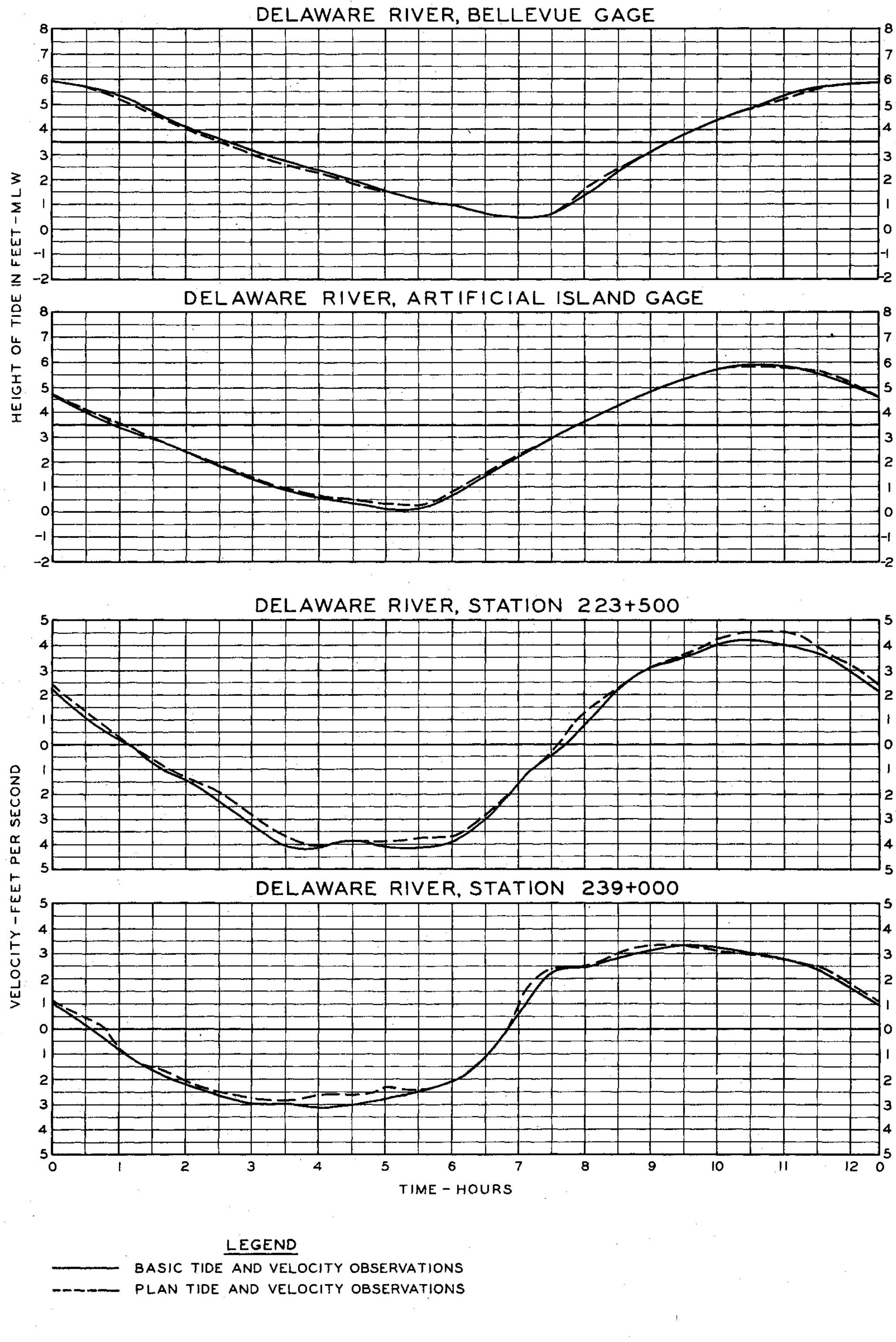
TIDE AND VELOCITY OBSERVATIONS
PLAN I



NOTE: TIME IS EXPRESSED IN HOURS AFTER THE MOON'S TRANSIT OVER GREENWICH, LESS FIVE HOURS.

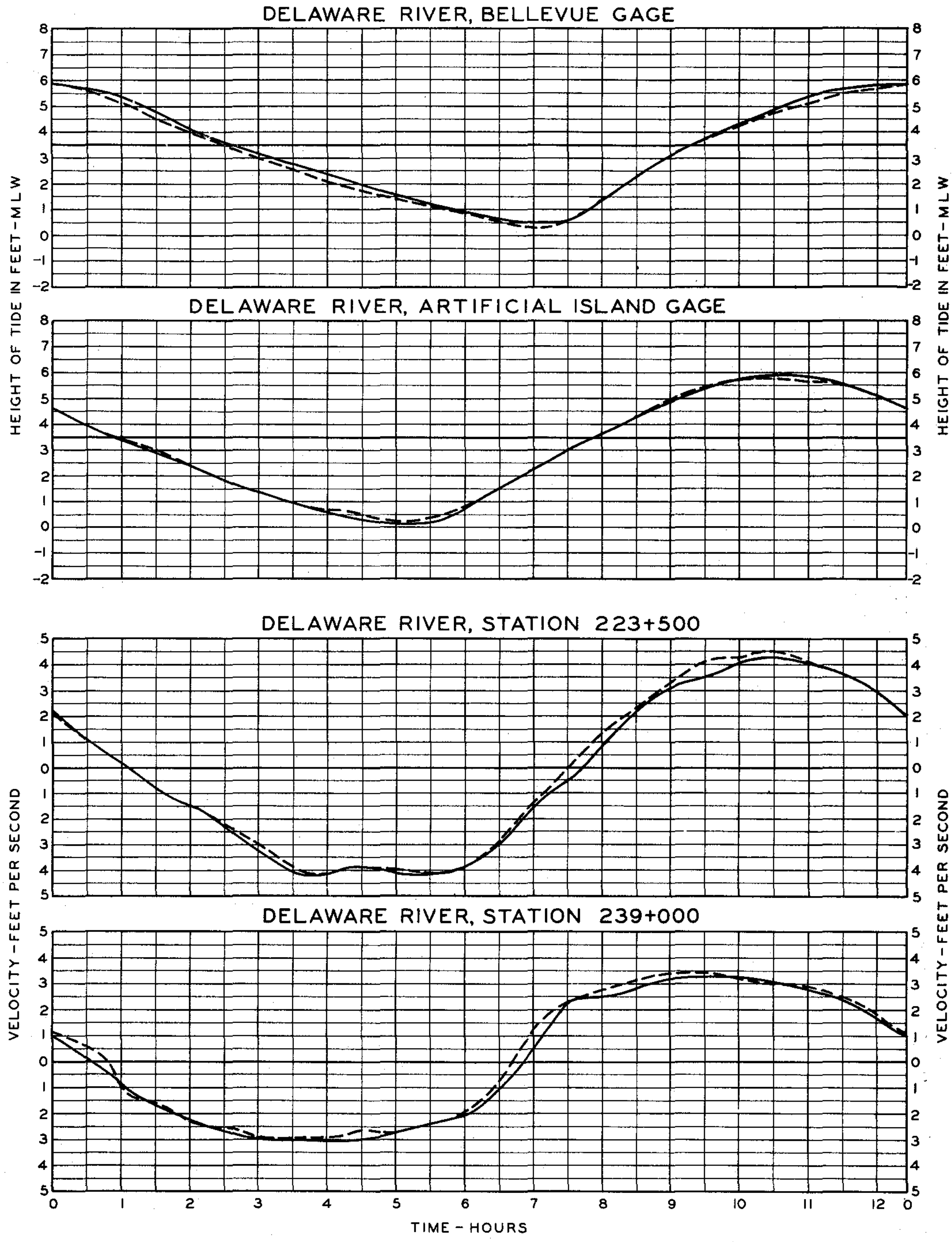
TIDE AND VELOCITY OBSERVATIONS
PLAN 2A

PLATE 10



NOTE: TIME IS EXPRESSED IN HOURS AFTER THE MOON'S TRANSIT OVER GREENWICH, LESS FIVE HOURS.

TIDE AND VELOCITY OBSERVATIONS
PLAN 2B



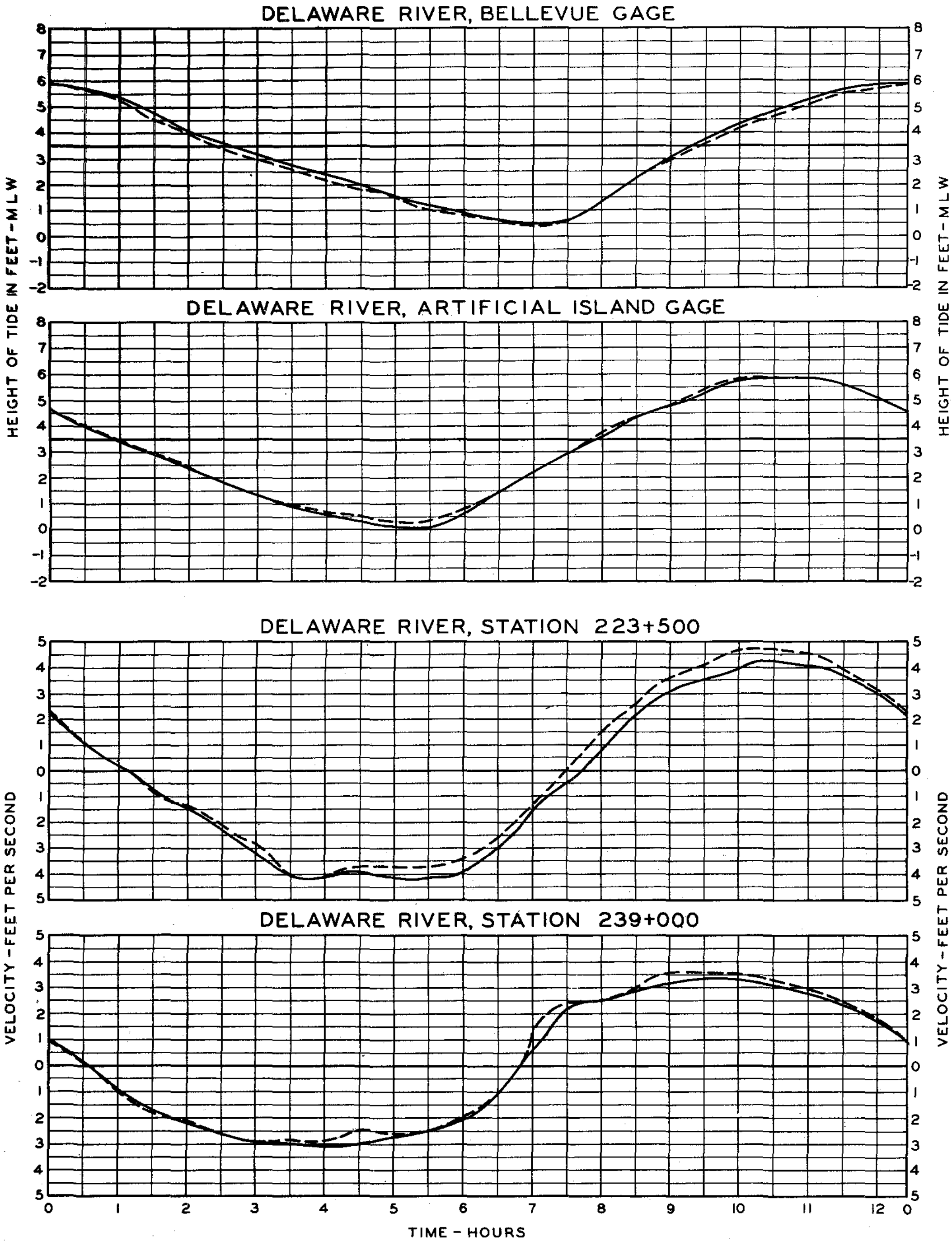
LEGEND

—————— BASIC TIDE AND VELOCITY OBSERVATIONS

- - - - - - PLAN TIDE AND VELOCITY OBSERVATIONS

NOTE: TIME IS EXPRESSED IN HOURS AFTER THE MOON'S TRANSIT OVER GREENWICH, LESS FIVE HOURS.

TIDE AND VELOCITY OBSERVATIONS
PLAN 3



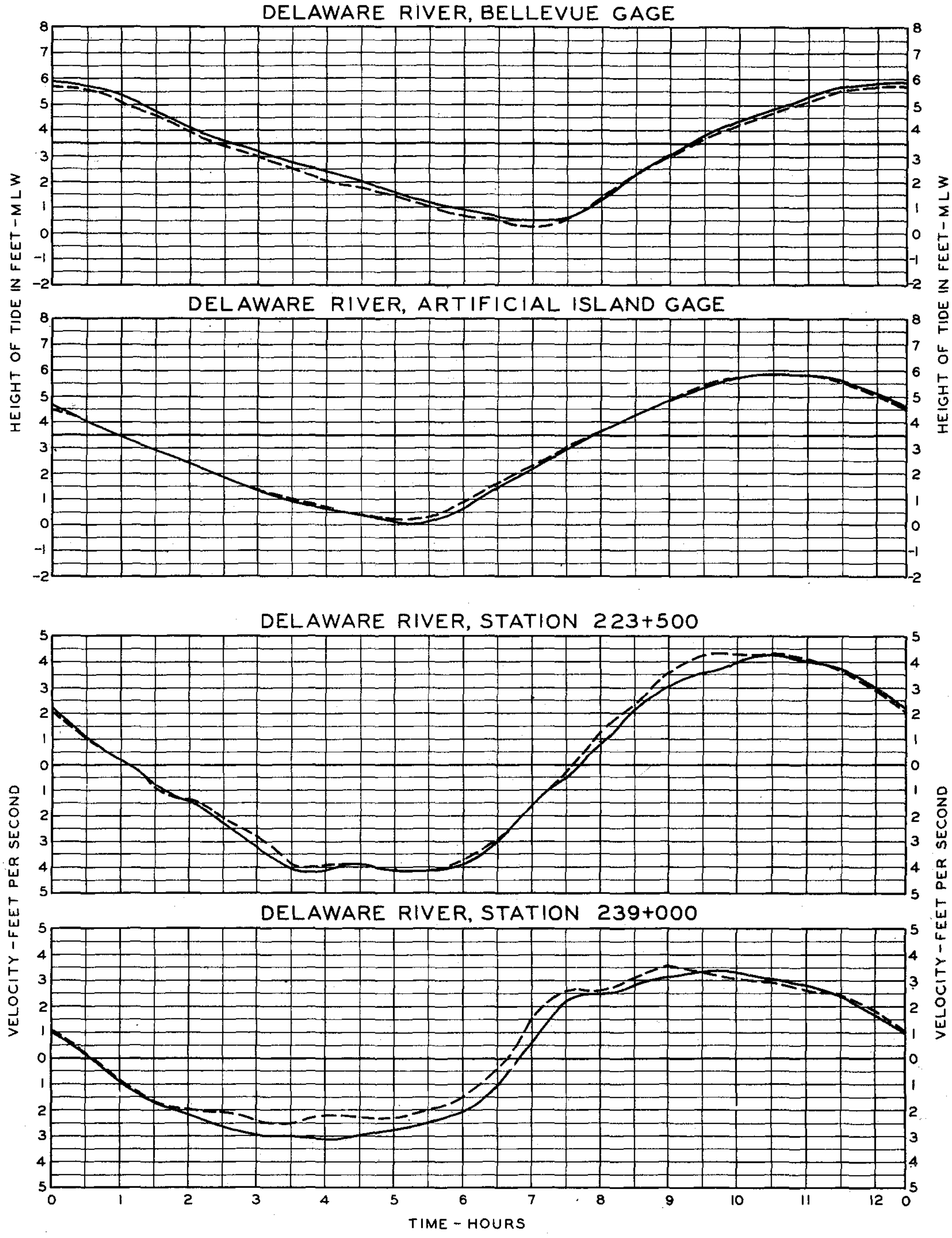
LEGEND

——— BASIC TIDE AND VELOCITY OBSERVATIONS

------ PLAN TIDE AND VELOCITY OBSERVATIONS

NOTE: TIME IS EXPRESSED IN HOURS AFTER THE MOON'S TRANSIT OVER GREENWICH, LESS FIVE HOURS.

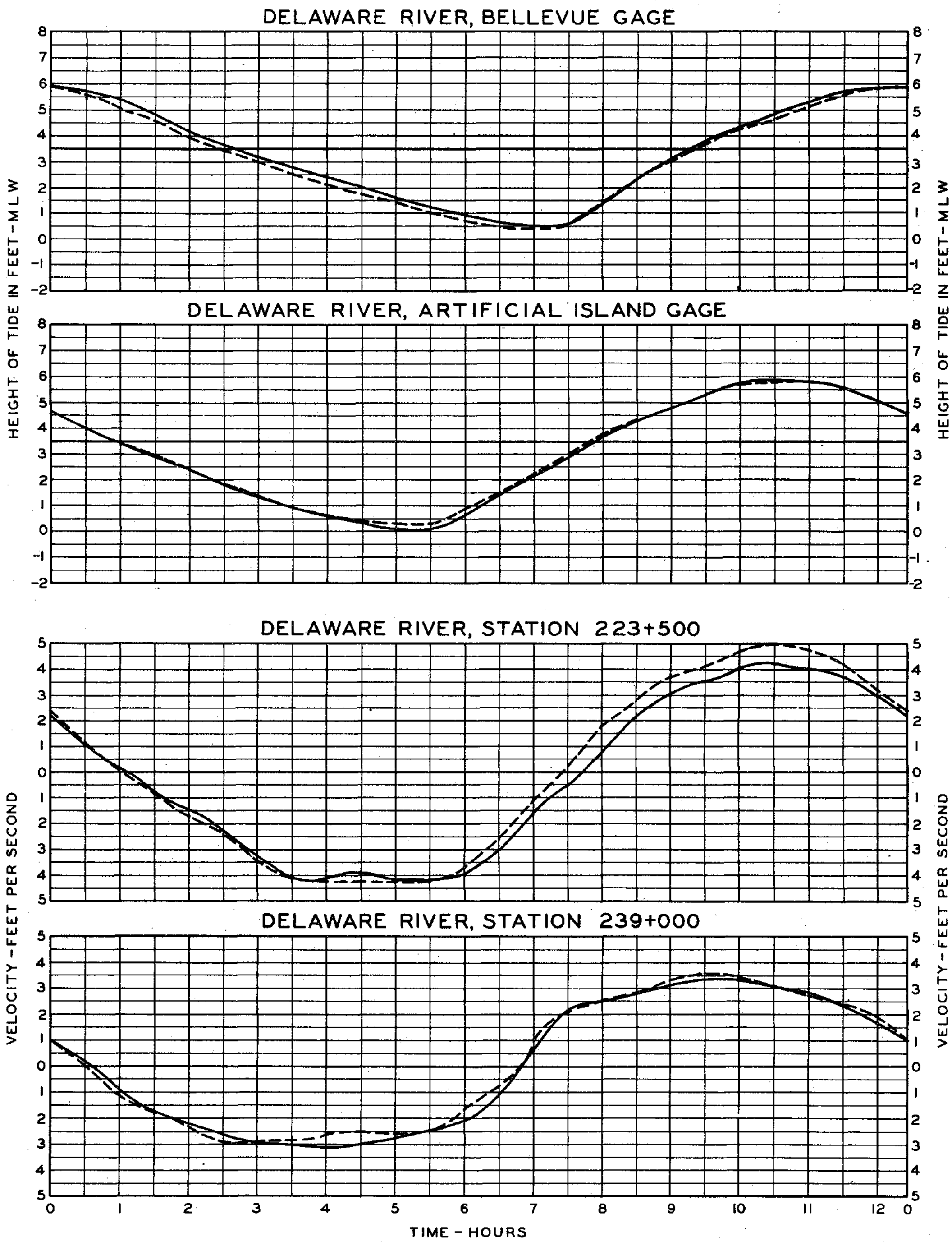
TIDE AND VELOCITY OBSERVATIONS
PLAN 4



LEGEND
——— BASIC TIDE AND VELOCITY OBSERVATIONS
- - - - PLAN TIDE AND VELOCITY OBSERVATIONS

NOTE: TIME IS EXPRESSED IN HOURS AFTER THE MOON'S TRANSIT OVER GREENWICH, LESS FIVE HOURS.

TIDE AND VELOCITY OBSERVATIONS
PLAN 5



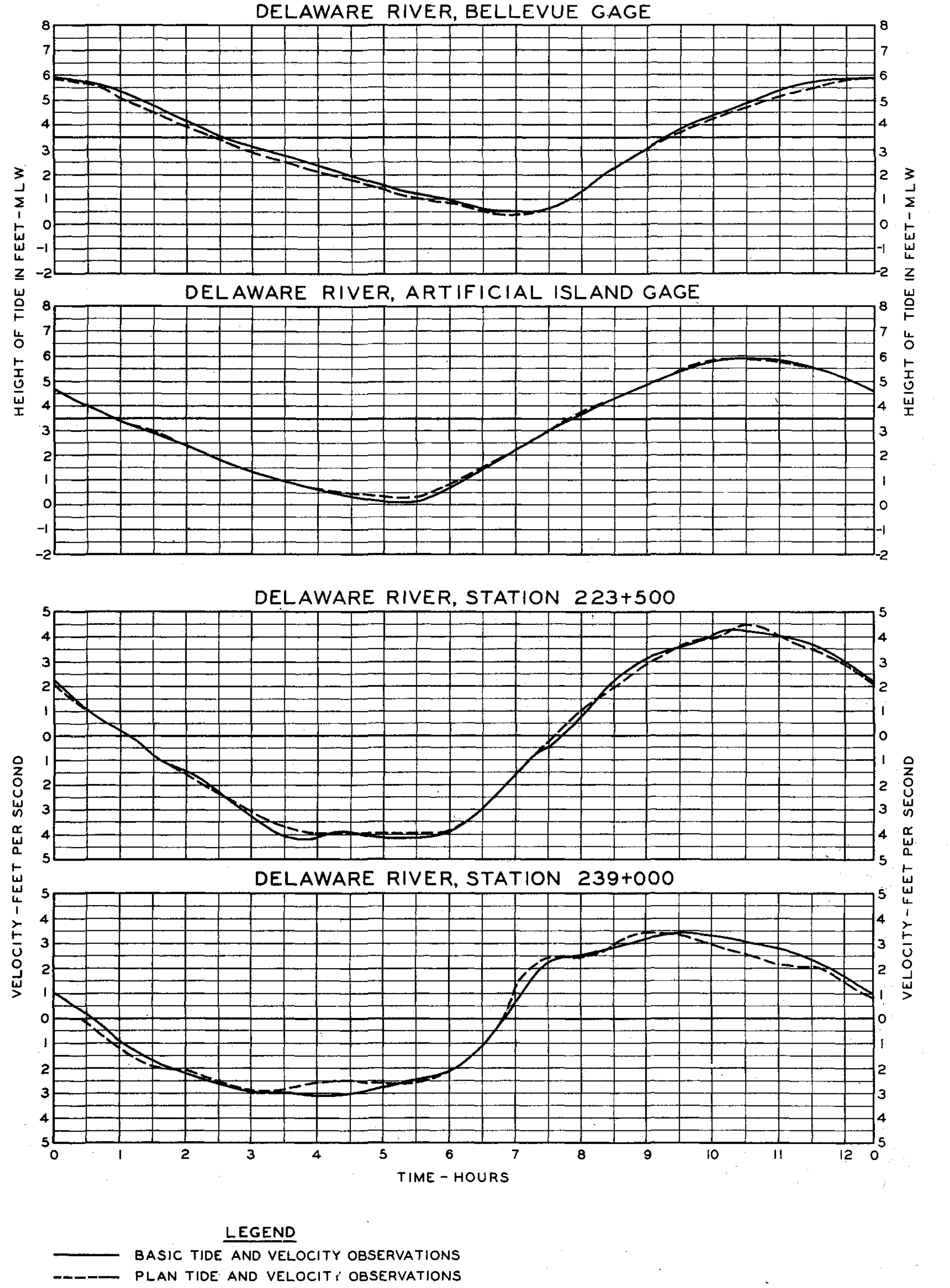
LEGEND

——— BASIC TIDE AND VELOCITY OBSERVATIONS

- - - - PLAN TIDE AND VELOCITY OBSERVATIONS

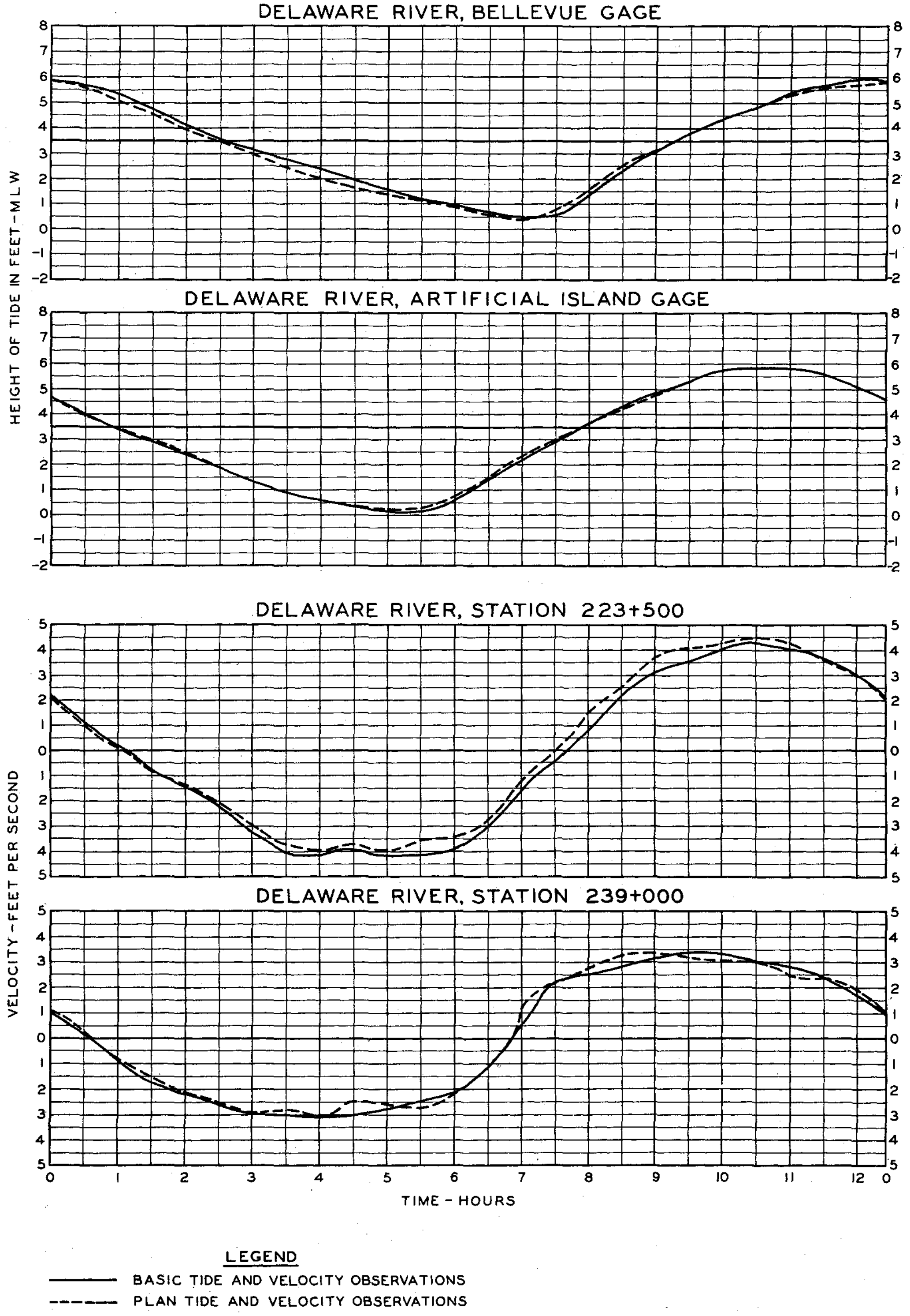
NOTE: TIME IS EXPRESSED IN HOURS AFTER THE MOON'S TRANSIT OVER GREENWICH, LESS FIVE HOURS.

TIDE AND VELOCITY OBSERVATIONS
PLAN 6



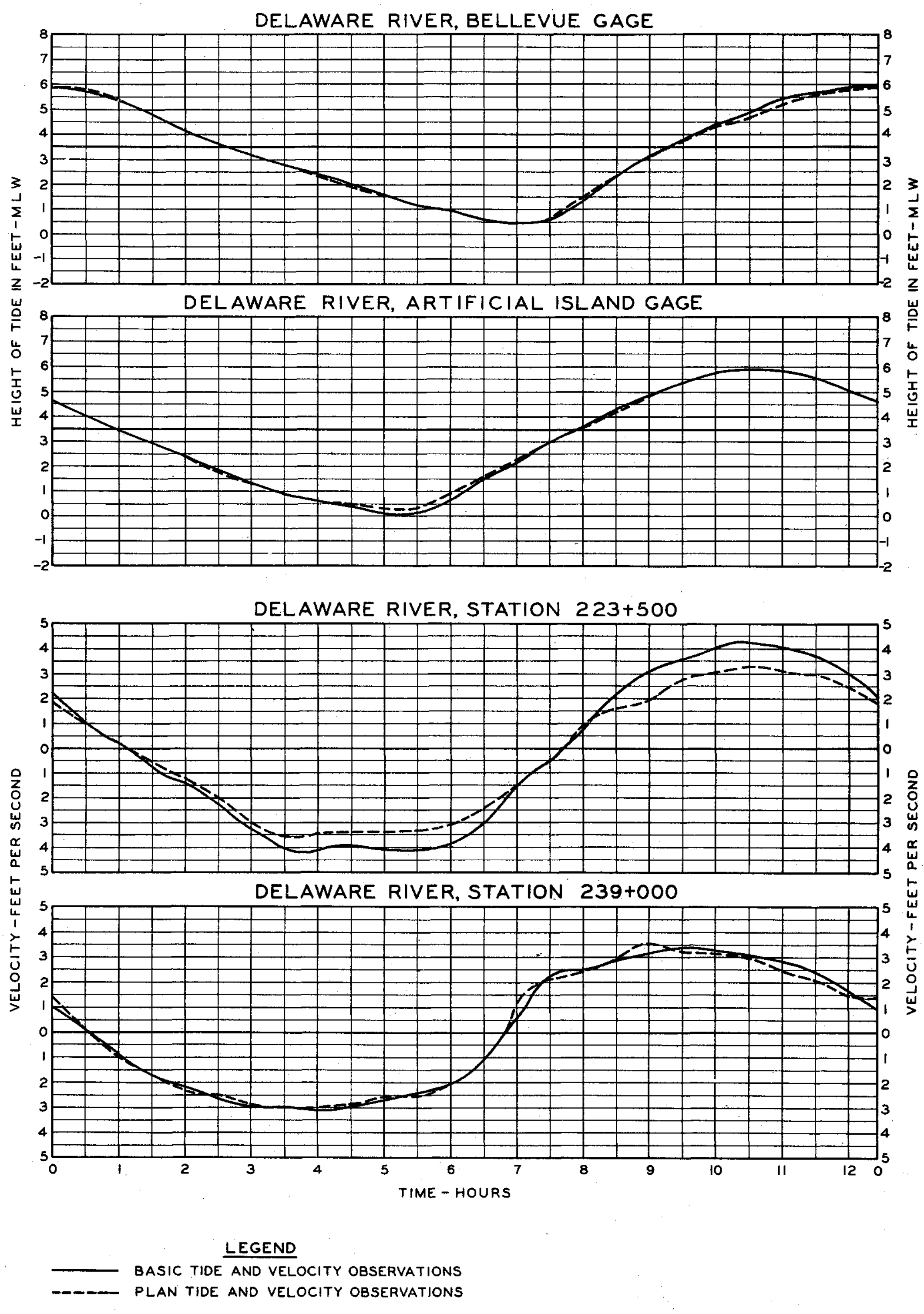
NOTE: TIME IS EXPRESSED IN HOURS AFTER THE MOON'S TRANSIT OVER GREENWICH, LESS FIVE HOURS.

TIDE AND VELOCITY OBSERVATIONS
PLAN 7



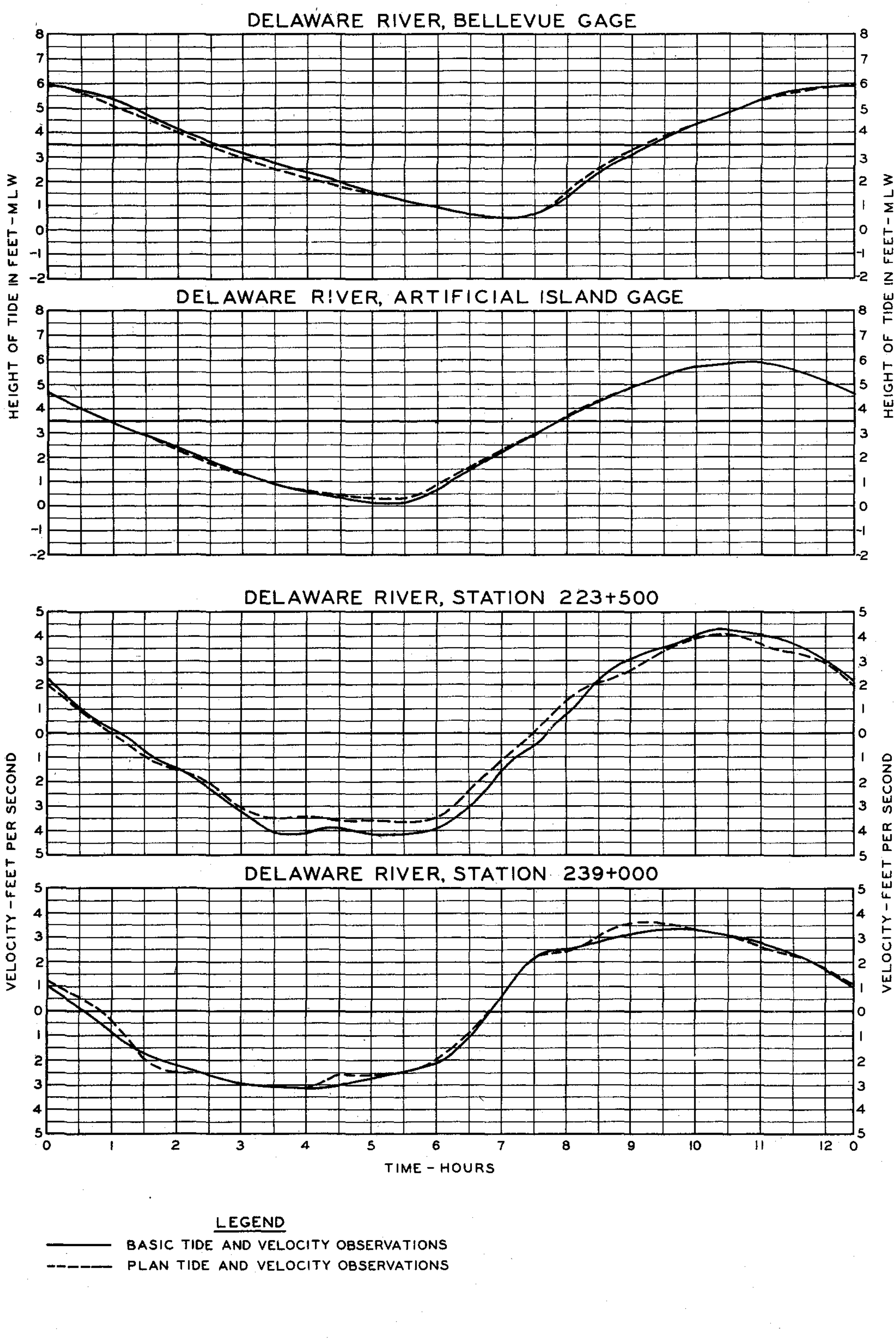
NOTE: TIME IS EXPRESSED IN HOURS AFTER THE MOON'S TRANSIT OVER GREENWICH, LESS FIVE HOURS.

TIDE AND VELOCITY OBSERVATIONS
PLAN 8



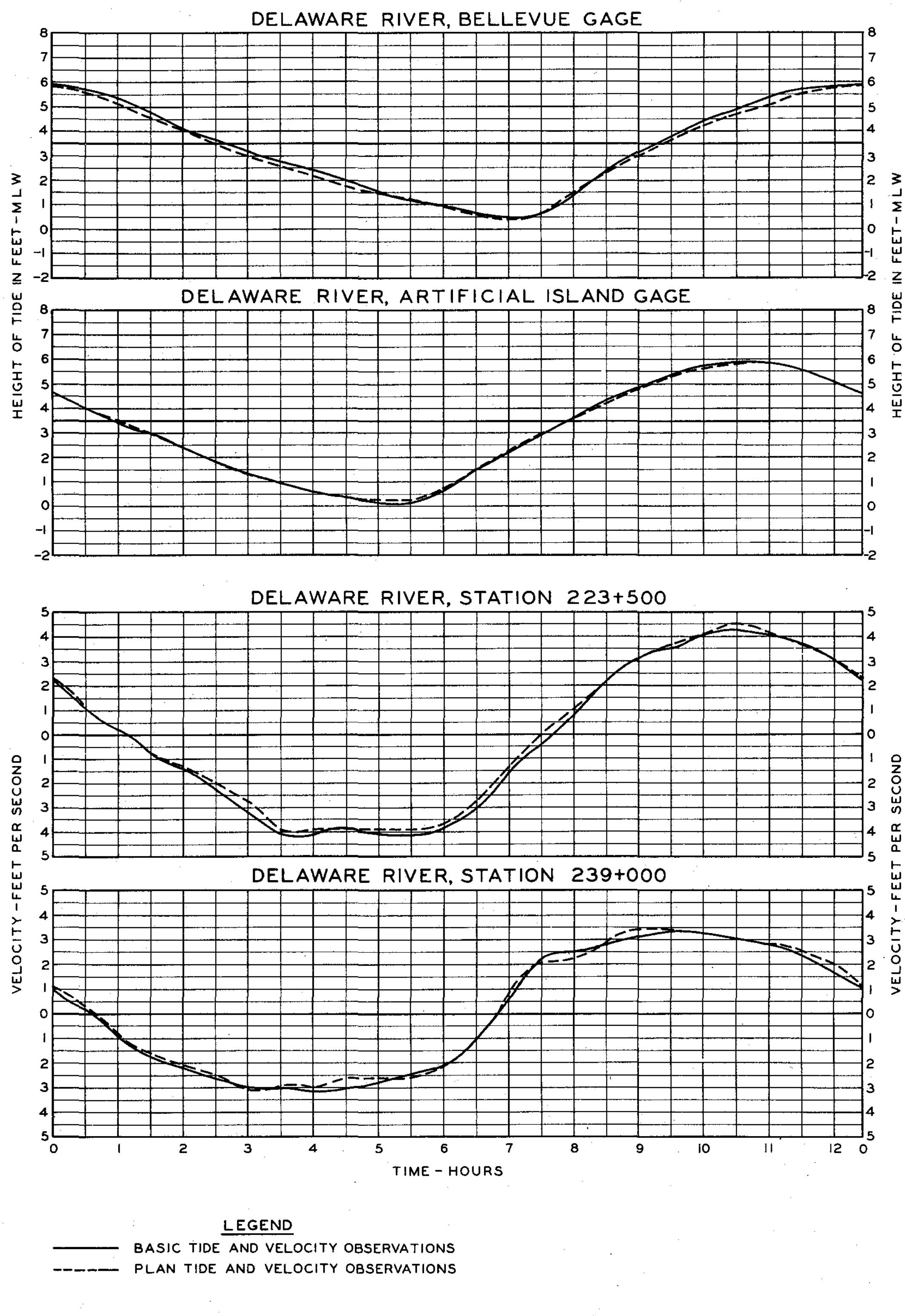
NOTE: TIME IS EXPRESSED IN HOURS AFTER THE MOON'S TRANSIT OVER GREENWICH, LESS FIVE HOURS.

TIDE AND VELOCITY OBSERVATIONS
PLAN 17



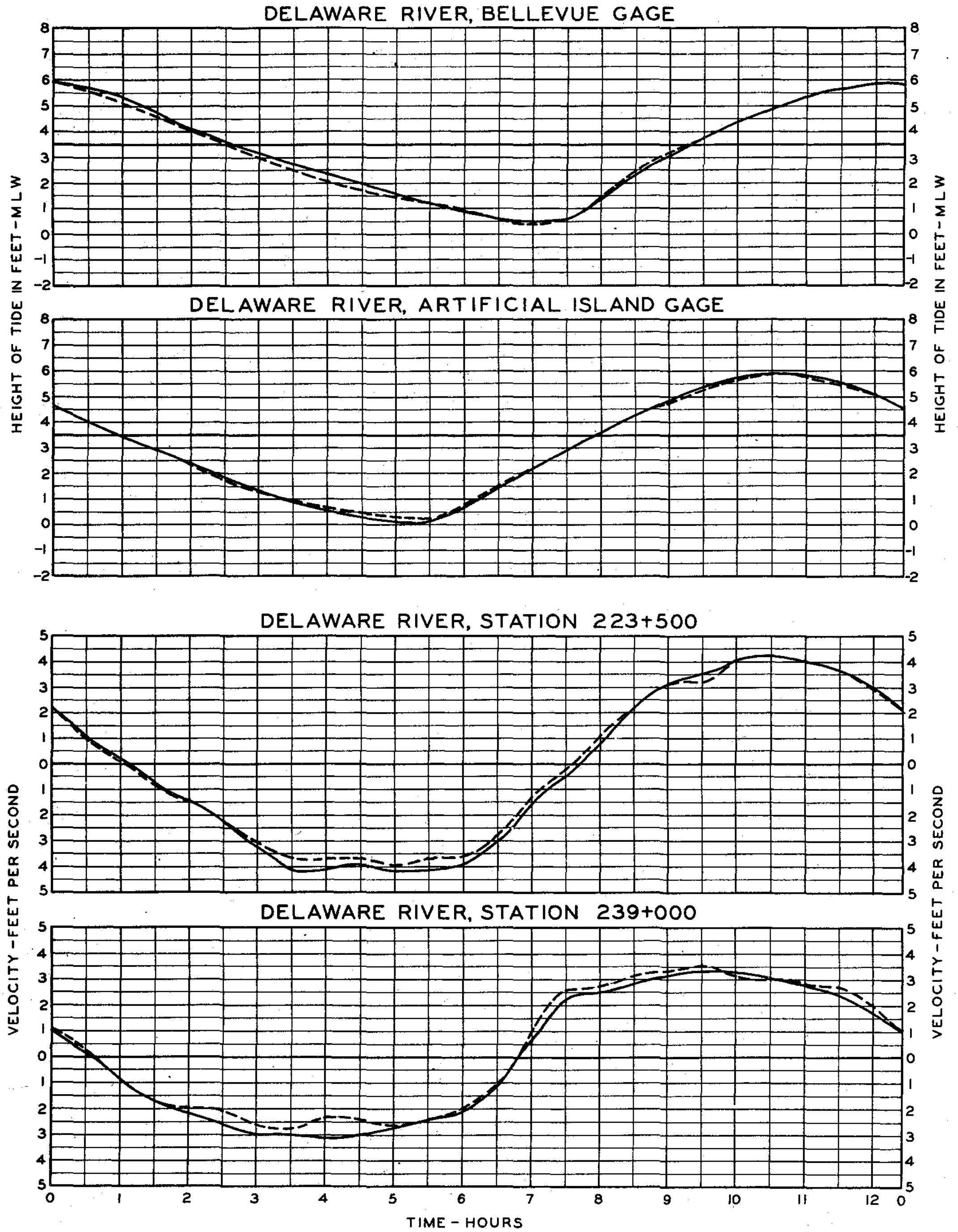
NOTE: TIME IS EXPRESSED IN HOURS AFTER THE MOON'S TRANSIT OVER GREENWICH, LESS FIVE HOURS.

TIDE AND VELOCITY OBSERVATIONS
PLAN 18



NOTE: TIME IS EXPRESSED IN HOURS AFTER THE MOON'S TRANSIT OVER GREENWICH, LESS FIVE HOURS.

TIDE AND VELOCITY OBSERVATIONS
PLAN 19



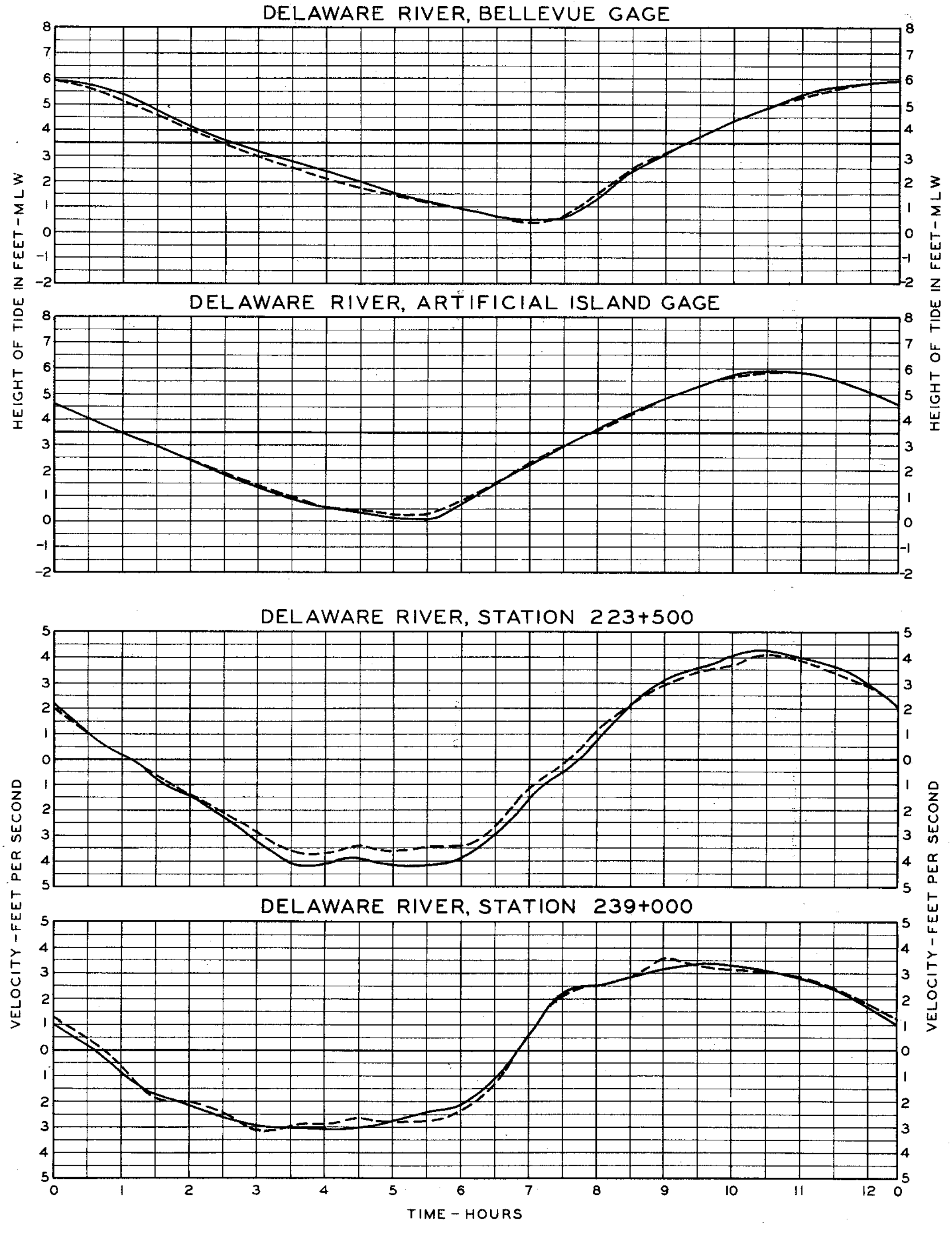
LEGEND

——— BASIC TIDE AND VELOCITY OBSERVATIONS

- - - - PLAN TIDE AND VELOCITY OBSERVATIONS

NOTE: TIME IS EXPRESSED IN HOURS AFTER THE MOON'S TRANSIT OVER GREENWICH, LESS FIVE HOURS.

TIDE AND VELOCITY OBSERVATIONS
PLAN 20



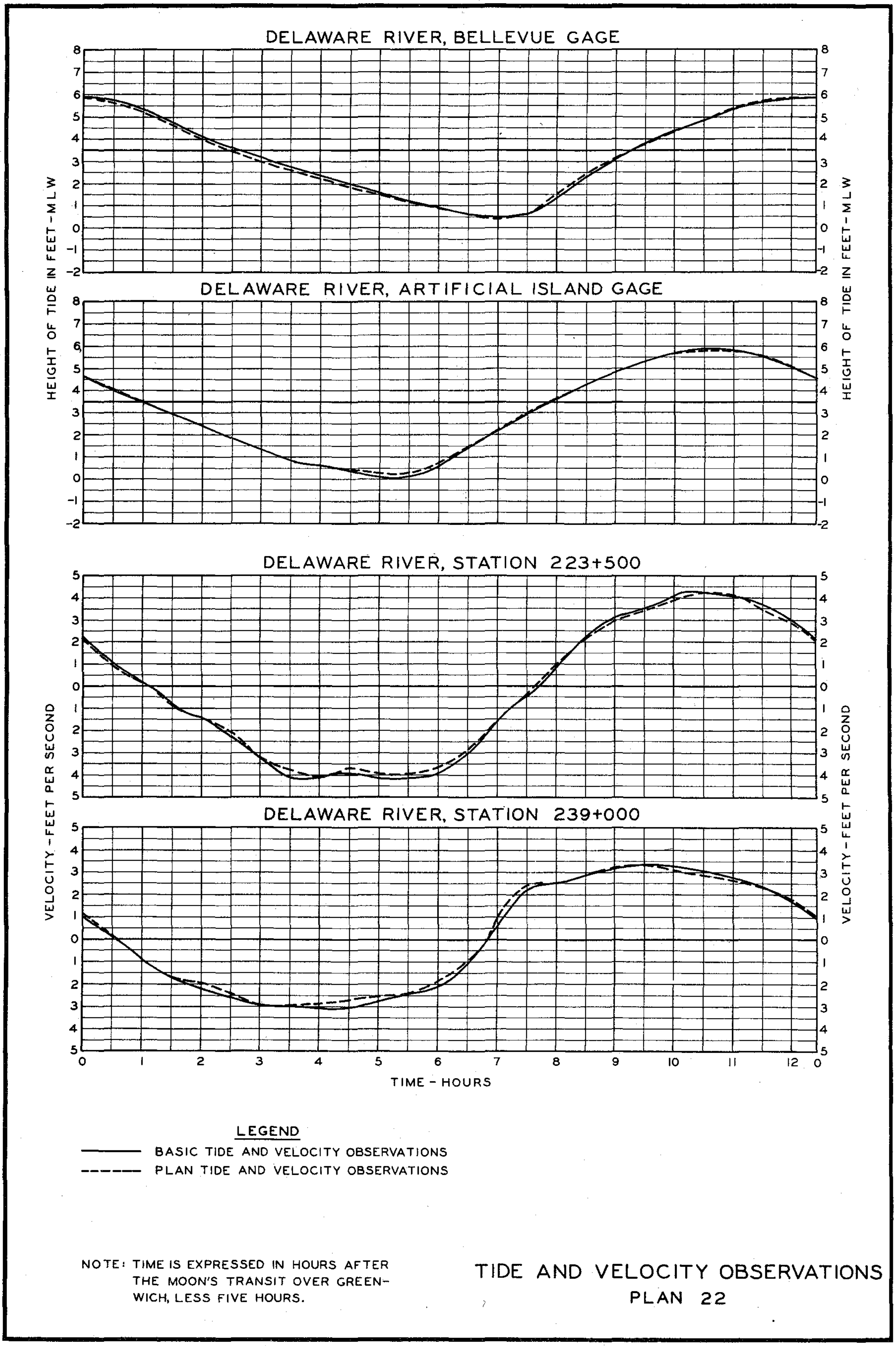
LEGEND

BASIC TIDE AND VELOCITY OBSERVATIONS

PLAN TIDE AND VELOCITY OBSERVATIONS

NOTE: TIME IS EXPRESSED IN HOURS AFTER THE MOON'S TRANSIT OVER GREENWICH, LESS FIVE HOURS.

TIDE AND VELOCITY OBSERVATIONS
PLAN 21


DELAWARE RIVER, BELLEVUE GAGE
DELAWARE RIVER, ARTIFICIAL ISLAND GAGE
HEIGHT OF TIDE IN FEET-MLW
DELAWARE RIVER, STATION 223+500
DELAWARE RIVER, STATION 239+000
VELOCITY-FEET PER SECOND
TIME - HOURS
LEGEND
BASIC TIDE AND VELOCITY OBSERVATIONS
PLAN TIDE AND VELOCITY OBSERVATIONS
NOTE: TIME IS EXPRESSED IN HOURS AFTER THE MOON'S TRANSIT OVER GREENWICH, LESS FIVE HOURS.
TIDE AND VELOCITY OBSERVATIONS
PLAN 22